United States
Department of
Agriculture

Forest Service

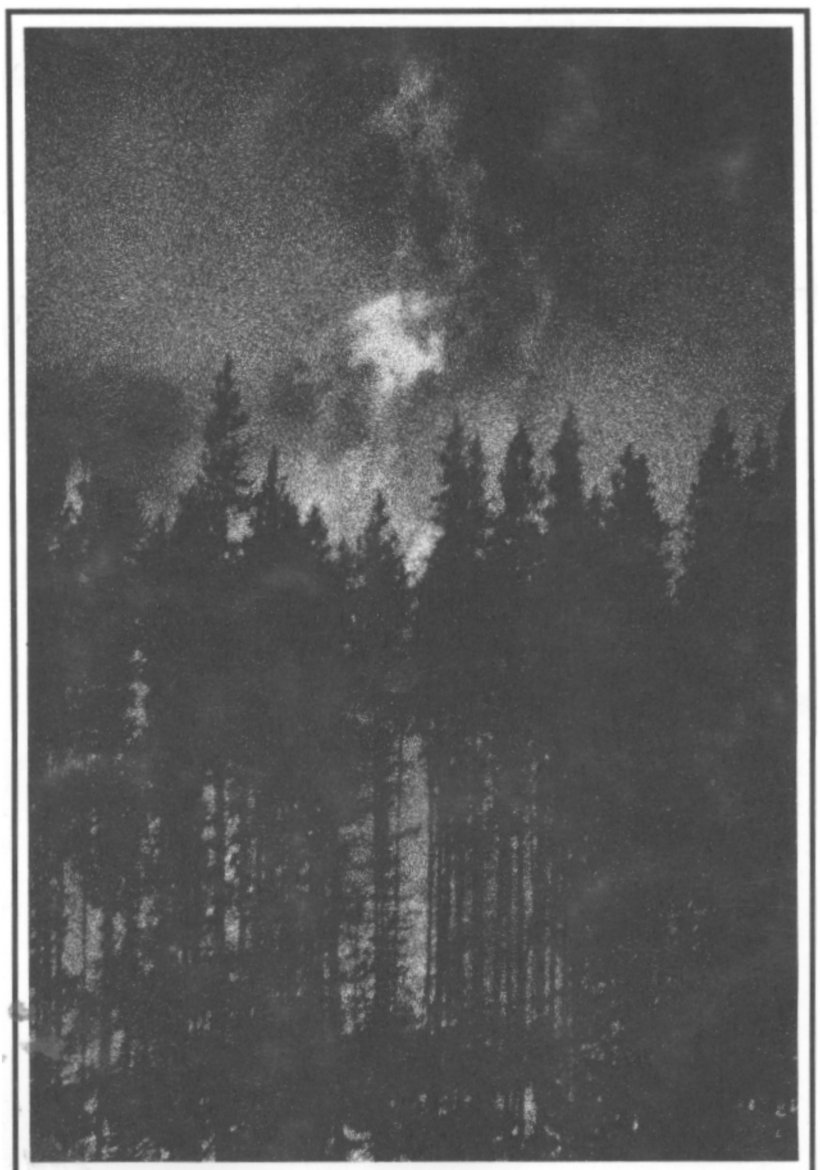
**Pacific Southwest
Forest and Range
Experiment Station**

General Technical
Report PSW-109

Proceedings of the Symposium on Fire and Watershed Management

October 26-28, 1988, Sacramento, California

Neil H. Berg, Technical Coordinator



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Publisher:

Pacific Southwest Forest and Range Experiment Station
P.O. Box 245, Berkeley, California 94701

March 1989

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FOREWORD

Wildfires have affected the landscape since the dawn of time and will continue to do so for the foreseeable future. Policies and practices in response to fire have varied, however, contingent upon a complex mix of values and attitudes overlaid by the technical acumen available to both "fight" the fire and reclaim the land afterwards.

Massive wildland fires along the west coast of the United States during summer 1987 were the impetus for selection of Fire and Watershed Management as the theme for the second biennial conference of the Watershed Management Council. Consumption of a major portion of Yellowstone National Park by wildfire in 1988 prompted national attention on fire containment and control policies and elevated the significance of the Symposium and Field Tour.

After the success of the California Watershed Management Conference in November 1986, a steering group was formed to plan and organize the second conference. Session topics were selected to identify major issues currently affecting the development of policies and procedures in the area of fire and watershed management. The topics were land use decisions and fire risk, effects of fire on watersheds, and resource recovery (emergency rehabilitation and long-term restoration). Each topic was examined during half-day symposiums at which information was presented by 25 invited experts. Their papers represent a unique assemblage of knowledge, viewpoints, and methodologies. Included are perspectives from research, technology applications, and land and resource management. The Symposium also provided opportunities for in-depth, one-on-one discussions as part of the presentation of 15 poster papers. In addition, Paul Barker, Forest Service, USDA, and Harold Walt, California State Board of Forestry, presented luncheon addresses.

To illustrate points developed in the Symposium and allow further informal interactions, a field tour of the Stanislaus Complex Burn, the largest contiguous area burned in California in 1987, was held after the Symposium. Stops on the tour emphasized emergency rehabilitation techniques, salvage timber harvest, and reforestation efforts and pointed out the often complex interplay of procedures and policies necessary to optimize resource recovery.

Principal sponsors of the Symposium were the California Department of Forestry and Fire Protection, Department of Forestry and Resource Management (University of California, Berkeley), East Bay Municipal Utility District, Pacific Gas and Electric Company, and Pacific Southwest Forest and Range Experiment Station (Forest Service, USDA). Other Symposium sponsors included the California Department of Conservation (Division of Mines and Geology), Jones and Stokes Associates, Inc., Meridian Engineering, Inc., National Council of the Paper Industry for Air and Stream Improvement, Inc., Operation Phoenix, Pacific Southwest Region (Forest Service, USDA), Soil Conservation Service, USDA, US Environmental Protection Agency, Water Resources Center (University of California), and Wildland Resources Center (University of California). The Stanislaus National Forest (Forest Service, USDA) sponsored the field tour.

To expedite publication of the proceedings, we asked authors to assume full responsibility for delivering their manuscripts in photoready format by the time the conference convened. We thank all the presentors who took the time to prepare their presentations for this volume and recognize the difficulty of converting a poster presentation to a manuscript.

Without the tireless and dedicated effort of the program staff, Theodore Adams (field trip), Linton Bowie (publicity), Trinda Bedrossian (at large), Robert Doty (posters, technical program, field trip), Johannes DeVries (at large), Ed Dunkley (at large), James Frazier (field trip), Charles Hazel (local arrangements, exhibits), George Ice (technical program), Kimberly Lathrop (technical program), John Munn (technical program), Carol Walker (registration), and Ed Wallace (at large), neither the symposium nor the field tour would have occurred.

Special thanks are due May Huddleston, Stanley Scher, and Sandy Young for editing these proceedings and to the Pacific Gas and Electric Company for producing and distributing the bulk of the publicity materials.

Neil H. Berg
Technical Coordinator
Pacific Southwest Forest and Range Experiment Station, Forest Service USDA

OPENING REMARKS

WELCOME! It is a real pleasure for me to welcome you to the second biennial Watershed Management Conference. Just think, just two short years ago many of us were gathered here in Sacramento for the first conference. That first conference was a huge success, and I believe that this second biennial conference will follow suit.

The goal in organizing this conference is to provide a forum for discussing the problems, experiences, and needs for changes related to fire and watershed management. The fires of fall 1987, in Oregon and California, jolted us into the realization of just how vulnerable our watersheds are to wildfires—thus, the reason for us to choose "Fire and Watershed Management" as the theme of this second biennial conference.

Just a quick check of the program tells you that an excellent exchange of information on watershed management is in store for us. The symposium planning committee, chaired by Neil Berg, has selected a number of papers relating to land use decisions that contribute to, or lessen, the risks of wildfire. Other selected papers will present some new information as well as reemphasize the effects that fire has on watershed properties. Then a group of papers will explore ways of rehabilitating watersheds that have been ravaged by wildfire, to restore their favorable hydrologic function.

The planning committee has provided, between the major sections of the symposium, ample opportunities for discussion with your fellow colleagues and a chance to renew old acquaintances. The exhibits will provide a look at new technologies. Although we usually do not hesitate to share our views openly, the wine tasting will loosen us up for some frank discussions. The poster session will provide a welcome break between sessions and again give us a chance to exchange information on a one-on-one basis. The Fire Flicks Film Festival will provide a multimedia forum for transferring knowledge and information. I believe that a real top-notch symposium is in store for us.

At the end of the symposium, we have a field trip to the Stanislaus National Forest to get that "on the ground" look and experience that just can't be provided in a ballroom. Again, we will have a chance to discuss and exchange ideas with our peers, while observing the challenges that wildfire imposes on our routine life in watershed management.

In summary, I think we have an enjoyable, informative and productive four days ahead of us. But, let's not just sit back and assume that the authors presenting the papers are providing all the answers. As the papers are presented, ask yourselves, "What management options do we need to pursue to make watersheds less susceptible to wildfire? Are changes in fuels management needed? What are they? How do we put them into practice? What new research is needed?" Let's go away from here, not with just the knowledge of how to fix it—but, let's constantly look ahead and seek out ways to improve watershed management.

You are the best brains in watershed management, and you are the most experienced cadre to meet the challenges ahead.

Let's use this time to take a break from the hectic year that we have all put in to recover from last year's holocausts. Kick back, give the authors your attention, absorb the experience and information that they have for you, pursue some active discussions while looking at the exhibits and posters, and use your newly gained knowledge for better watershed management in future years.

Again, welcome! It is good to see you all again.

Andrew A. Leven
Executive Committee Chair, Watershed Management Council
Assistant Regional Forester, Range and Watershed Management
Pacific Southwest Region, Forest Service, USDA

Timber Salvage Operations and Watershed Resource Values[1]

Paul F. Barker[2]

In 1987 we had the most extensive and destructive wildfires ever to hit the National Forests in California. More than 700,000 acres of National Forest land in the Sierra Nevada and Northern California burned, and 1.8 billion board feet of timber was damaged or killed.

Fire intensity was so severe that rates of tree kill were as much as 40 percent in some stands. As a result, salvage logging of severely damaged stands became a major priority in the Pacific Southwest Region, and salvage logging made up nearly half of the total timber harvest in 1988.

The fires were of particular concern because the 20 million acres of National Forest land in California supply nearly half the surface water available for homes, farms, and communities in the State.

EMERGENCY REHABILITATION

The firefighters received much-deserved credit for their heroic efforts to protect lives, property, and resources during those fires. Unfortunately, the rehabilitation crews that went in after the fires to protect watersheds from further damage got much less attention.

Emergency rehabilitation measures began right after the fires and included the following:

- seeding 78,000 acres of intensely burned lands with grass and forbs to establish protective cover

- contour felling of dead standing trees on about 3,000 acres to retard downslope water runoff

- clearing about 70 miles of stream channels of debris that could plug culverts and damage bridges

- restoring drainage along about 1,000 miles of roads to handle increased runoff from winter rains

- installing more than 2,000 structures to trap sediment, stabilize streambanks, and reduce gully erosion

Emergency rehabilitation cost over $5 million over a period of three months. Watershed restoration and fisheries habitat work continued throughout the year and more than $1 million has been spent on restoration projects in 1988.

SALVAGE LOGGING

I think these few facts show that the Region is committed to preserving watershed resource values. However, earlier this year there was a lot of press coverage of public concerns about the potential adverse effects of salvage logging on National Forest watersheds. Many of our salvage timber sales were challenged.

Today I'd like to put salvage logging on the National Forests in perspective.

Timber harvest from National Forests in California averages 1.8 billion board feet annually. In normal years salvage makes up less than 5 percent of timber harvest. As a result of the 1987 fires, salvage made up an unusually large percentage of the harvest in 1988, amounting to about 50 percent of the total. However, harvest of green timber was reduced proportionately so that the total volume harvested from National Forests remained close to the historic average of 1.8 billion board feet.

Salvage logging is an emergency measure that requires timely removal of the fire-damaged trees before they deteriorate. Normal timber harvest planning extends over a 5-year period, but we do not have that kind of time available in salvage logging. Although it is important to salvage fire damaged trees before they become unmarketable due to insect damage and disease, we cannot afford to take shortcuts which will result in further damage to the watershed resources in the area.

Once a wildfire passes through an area, protective cover is reduced, the area is

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[1] Presented at the Symposium on Fire and Watershed Management, October 26-28, 1988, Sacramento, California.

[2] Regional Forester, Pacific Southwest Region, Forest Service, U.S. Department of Agriculture, San Francisco, California

subjected to increased raindrop impact, and in some cases there is a loss of soil infiltration capacity. All of this results in more rapid runoff, gullying, and subsequent water quality degradation. In many cases, we no longer have that "green" strip of vegetation along the stream channels to filter out sediment, and slow down the flow of water.

In preparing salvage sales, the Forest Service looks at the cumulative effects on the watershed caused by the fire, and those likely to occur as a result of salvage logging. The total environmental assessment includes benefits that can be derived from salvage logging as well as the negative effect salvage might have. The same care and attention to resource values occurs in planning salvage sales. Only the much shorter time available to complete salvage sales distinguishes them from normal green timber sales.

Total salvage from the 1987 fires will amount to about 1.2 billion board feet over the next couple of years. Green sales will be reduced during this period, and only about 200,000 acres of the total 700,000 burned acres will be salvage logged. That is a very small percentage of the total 6-million acres of National Forest land in California considered available and suitable for timber production.

So what becomes of the areas that are not salvaged?

Watershed restoration work will continue in those areas. This year and for the next 2 to 3 years, $2 to $3 million will be spent on watershed restoration work.

In the past, only emergency watershed restoration and salvage dollars were appropriated by Congress. This year additional appropriations for watershed and wildlife habitat restoration were authorized to work on additional acres that could not be covered under the emergency funding authorization.

BENEFITS OF SALVAGE LOGGING TO WATERSHEDS

Potential adverse effects of salvage logging have been discussed at length. What about the benefits of salvage logging?

The most obvious benefit is that valuable timber will be used for wood products rather than just deteriorate. But equally important, salvage can return significant benefits to the many resources in the burned areas.

Unsalvaged-dead trees are susceptible to insect and disease infestations, and can represent a threat to the remaining live trees and adjacent stands. In addition, standing-dead trees provide little protection to the watershed. Slash that remains on the ground following salvage logging can provide mulch to an otherwise bare landscape, and during salvage, a certain number of trees are felled on the contour, and left on the ground as a watershed protection measure.

In many areas, large volumes of woody debris deposited in drainages as a result of wildfires are removed as part of salvage operations, while at the same time leaving logs in stream channels where such measures will stabilize channels and improve fish habitat.

Timber salvage operations provide needed dollars for long term watershed restoration and may be the most important contribution to watershed recovery after a fire.

Emergency funds for rehabilitation are limited to treatments that are emergency in nature. Although the amount of emergency funds available may be large, only a small area of a watershed is usually treated with those funds.

Road erosion is a common water pollution problem. As part of salvage operations, roads can be resurfaced and culverts upgraded or given needed maintenance. Roads opened for salvage logging can also provide vital access to conduct other watershed restoration work.

An important part of all salvage sales is collecting funds assessed to carry out erosion control. Erosion control measures are a normal part of any salvage sale contract.

Often overlooked is the fact that without salvage sales, the above benefits will not be accomplished because our budgets seldom provide funds for recovery beyond the dollars available for emergency rehabilitation. This is an important factor in analyzing cumulative effects.

Salvage, when done properly, and I can assure you the Forests are doing a great job in "doing it properly," adds little if any additional impact and serves to reduce the long term cumulative watershed impacts already imposed on the watershed by wildfire. Salvage actually speeds up revegetation and reduces the time it takes for the watershed to recover its hydrologic function. Improvements to roads and channels and other erosion measures also reduce the overall cumulative impacts in a watershed.

CONCLUSION

Salvage logging, properly planned and carried out, provides important benefits to watersheds. The Forest Service is carrying out salvage with full consideration of watershed values. We are using salvage logging as an opportunity to carry out major restoration projects to benefit fish, wildlife, soils, and water resources on the National Forests.

Thank you very much.

Current and Future Wildland Fire Protection Impacts of the Wildland-Urban Interface[1]

Harold R. Walt[2]

I want to first of all thank the Watershed Management Council for putting on this most timely and important conference. You must know that your specialized field is the Board of Forestry's absolute top priority for an expanded and enriched research effort, and we had strong bipartisan support from the Legislature to fund the start of such a program beginning in 1988-89, but with so many budget pressures this year in Sacramento and the unexpected surge in enrollment at the University of California, we had to take a rain-check until next year.

Thank you, Andrew Leven, for the kind introduction. You may wonder how a school teacher specializing in banking has the temerity to stand up before a group of watershed specialists. It's easy; I combine the two backgrounds: banking and forestry. Picture something along this line. It's October. The leaves are falling and I can't remember when I've seen so many stripped, bare and lifeless-looking branches. Particularly the ones belonging to savings and loan associations.

As you have heard, I was trained as a forester at Berkeley but made my living for years as president of a major architectural and engineering company. Governor Deukmejian appointed me as chairman of the State Board of Forestry nearly six years ago, with assurances that the assignment would require only one day a month of my time. This nine-member Board sits as the policy and regulatory body for the California Department of Forestry and Fire Protection. Perhaps of direct relevance to my talk, the Board has been more active during the last five years in developing policies related to wildfire and the wildland urban interface than at any time in its 102-year history. During this period, the Board has traveled extensively in rural California and has come to know first-hand the fire protection impacts of development.

For the next few minutes, I hope to inform you about some of these impacts and to try to convince you, both collectively and as individuals, to help the Board address some of these issues. We will need all the help we can get, particularly from you professionals.

There is much I could talk to you about on wildfire and watersheds--everything from controlled burning to revegetation after wildfire. I could even dwell on the point that watershed damage done by wildfire, at least as measured by the area of vegetation destroyed, exceeds the area harvested for timber by many times. But I am sure others have told you all about this.

The real title of my speech ought to be something like "Fire and Water Ain't Seen Nothing Yet--Just Wait for the Next Eleven Million People." More people! Remember this and you will know the source of most significant current and future issues related to watersheds, wildfire, and the wildland-urban interface. The driving force behind both watershed and wildfire protection policies in California increasingly will be population.

Let me refresh your memory. Current estimates place the State's population at about 28 million. State Department of Finance projections suggest that the number will be 33 million by the year 2000.and 39 million by the year 2020. What does this mean in magnitude? Look around the room. In your mind's eye, add 20 percent more people. This is the year 2000. Now add 40 percent more. This is the year 2020. All of you want water to drink, a place to live--preferably in the country for

[1]Presented at the symposium on Fire and Watershed Management, October 26-28, 1988, Sacramento, California.

[2]Chairman, California State Board of Forestry, Sacramento, California

many of you, beautiful scenery in which to recreate along with police and fire protection. But we have to provide it within a fixed area and with fewer per capita dollars spent than we now use.

Of much greater concern to watershed folks, this population growth has not been evenly distributed around the state. From 1980-87, 23 rural counties increased their population by nearly 24 percent while population in the other 35 counties grew by only 17 percent. The fastest growth rates took place in rural counties like Nevada, Lake, and Calaveras. There are now over 7 million Californians living in rural areas, double the number of ten years ago, involving something over 2 million residential and related structures. With relatively few changes over the next three decades, the same counties are projected to be growth leaders. We are looking at more than 10 million residents in rural California early next century. And not only are we getting more pressure to produce water, we are having more people living in the very areas that yield this water.

This has all been documented in an extensive forest and range survey by the Department of Forestry and Fire Protection that is hot off the press. It is entitled <u>California's Forest and Rangelands: Growing Conflict Over Changing Uses.</u> This is eye-opening stuff and should be required reading several times for everyone in this room. It only costs a 25-cent postage stamp. See me or contact the CDF Forest and Rangeland Resources Assessment Program for details.

Now let me share some statistics that you may not know about. They concern wildfire. The State has financial responsibility for protecting timber, watershed, and contiguous rangelands amounting to about 35.5 million acres (14.4 MM ha). These are called State Responsibility Areas and include all of the significant, privately owned watershed lands in the State. On these lands, we currently experience about 8,000 wildfire starts a year. For various reasons, the number of fire starts from all causes has increased 37 percent over the last decade, based on a 5-year moving average. If long-term trends continue, we can expect an average of 11,000 wildfire starts per year over the 1990's and as many as 15,000 wildfire starts per year in the first decade of next century. Forty percent of the acreage burned comes from people-caused fires. Of special concern is arson. Approximately one out of five wildfires is started by an arsonist. There is a direct statistical link between the number of people and the arson starts. The more people, the more arson starts.

You may wonder why I am focusing on the effects of more people in wildland areas in this talk. From the standpoint of a wildfire protection agency, people and their impacts are our most critical problem. Even without people, the climate and geography of California encourage wildfires. In fact our state's natural history shows much evidence of wildfires frequently burning huge acreages. Dry climate, mountainous terrain, hot summer days, and substantial winds set the stage for fast-starting and hot-burning wildfire. But people exacerbate the wildfire problem in several ways.

- They build residences and other structures in rural settings that are hazardous fire areas without understanding the real danger of wildfire.

- They expect, indeed, politically demand that these residences and communities be protected from wildfire. Thus fire agencies are under a political and moral obligation to try to protect life and property first from wildfire. This is despite a mandate to protect natural resources.

- The location of structures in wildland areas along ridges and in other areas changes the way wildfires must be handled. Fires must be fought in very complex circumstances which give first consideration to evacuation of people and to protection of property. Only lastly is consideration given to the positioning of forces and choice of tactics to control wildfire.

- Increased residential and commercial development, with its associated streets, lawns, landscaping, and island borders of unused natural vegetation alter the pattern of firespread. Structures, especially if they are built in a manner not conducive to fire safety, themselves become volatile fuel for a wildfire.

- Control of accumulated fuels by prescribed burning is more difficult because emerging land ownership patterns and attitudes of land owners complicate land management. Of course, here it is worth noting that our past policy over the last 50 years to stop most wildfire has added to our accumulated fuels. How serious is the problem of structures on watershed lands, you might ask? Very serious. In my lifetime, nearly 4,500 homes and structures have been destroyed by rural wildfire. Sixty percent of these losses have occurred since 1970 at a total damage cost of about 750 million dollars--roughly the same magnitude as total losses from earthquakes and floods during the same period.

The recent Forty-niner fire near Nevada City shows the situation graphically. Jerry Partain, Director of the Department of Forestry and Fire Protection, called this fire the classic interface fire of the 1990's. In a matter of minutes, said one observer, this conflagration changed from a wildfire to a "real estate fire" and led the San Francisco Chronicle to question if homes should even be built in areas so severely prone to wildfire. The fire was indeed a classic. There were narrow roads, streets and houses without identification, flammable materials, little reserve water, and a belief by homeowners that the fire could only happen to someone else. The total damage was in excess of 30 million dollars and involved over 150 homes. More than 33,000 acres (13,400 ha) of watershed lands were burned. During the first day and a half of the fire, the vast majority, if not all, of the wildland and structural fire engines were committed to structure protection, leaving the wildfire to extend and to threaten more homes and to destroy more natural resources. Structures and their location effectively "watered down," so to speak, the ability to initially attack and to control the fire.

Structures even complicate what is essentially a wildland fire. A good example is the Stanislaus Fire Complex in 1987 near Sonora in Tuolomne County. This fire burned over 160,000 acres (65,000 ha) of watershed, which was about a sixth of the total of 900,000 acres (364,000 ha) that burned in 1987. The fire threatened several towns, and under different circumstances might well have burned hundreds of structures. The threat of burning into residential areas, plus the actual existence of structures, changed the way the fire was fought and diverted firefighting resources away from protecting timber and watershed lands. It is hard to measure if the natural resource losses were greater because of the existence of structures, but they were a real factor in the fire.

Structural fire protection in State Responsibility Areas is somewhat fragmented and difficult to coordinate. In addition to the California Department of Forestry and Fire Protection (CDF), there are about 360 special fire districts and 160 volunteer companies. Major consolidation of existing independent fire agencies is not expected over the next decade, so problems of coordination will remain, or even accelerate. Further, in many places CDF, on a de facto basis, has become a rural fire organization that provides services not directly related to wildfire protection. These include, but are not limited to, structural protection, emergency services such as heart attacks or hazardous material spills, and public assistance calls. Often because of the location of its facilities and its cooperative relationships with local citizens, CDF is the single agency that is expected to respond to public needs. These pressures and expectations will continue as more people move to rural areas.

The Board of Forestry has been struggling with these impacts for the last six years. I have come to believe that there are no simple answers. However, I think that you, as watershed professionals and other specialists concerned about our watersheds, can play an important role as we try to address the impacts of wildfire. Let me suggest a few action items, both to make what I say more relevant and to summarize my comments.

First, it is imperative that we make rural residents aware of the threat of wildfire both to themselves and to the environment. Most people who move into the wildland areas have no idea of the damage that wildfire can and will do in rural California. Statistically, it is just a matter of time until these areas will burn. In addition, people just assume that a fire truck will roll up to their house and protect it if a wildfire is threatening. In reality, this may or may not be true.

State law now requires a 30-foot minimum clearance of flammable vegetation around structures in State Responsibility Areas. This recognizes that such clearance is probably the single most effective step that a homeowner may take. The key to this law is enforcement. About one-fourth of all homes inspected by fire agencies do not meet the 30-foot clearance requirement on the first inspection. Even after a third inspection 28 percent of the homes that did not comply still do not meet the requirement. This would be bad enough if we had a vigorous enforcement program. However, CDF and other fire agencies do not have the staff to carry out a strong inspection program. At best, only high-risk areas are inspected each year. Thus the first thing you could do would be to understand the need for clearance of flammable vegetation around structures in wildfire-prone areas and to strongly support the personnel and program necessary to get such clearance.

Second, we must have more thorough local planning for the effects of development related to wildfire. Current general planning law recognizes the threat of wildfire only to a very limited degree, and the treatment is superficial when compared to that given to flood and earthquake threats. Over 20 rural counties have little or no consideration of wildfire in their general plans. There is almost no discussion of the cumulative effect of subdivisions in worsening the threat of wildfire. There is little discussion of strategic fire defense improvements, such as landing places for helicopters, or of evacuation plans for people in the event of wildfire. Intellectually, these kinds of analyses are old hat to watershed planners, but can be scary to local politicians and be viewed as very costly by developers.

Last year the Board of Forestry sponsored SB 2190 by Senators Dills and Campbell. The bill strengthened the requirements for general plans to deal with wildfire-related concerns. However, despite the support of fire agencies, planners, and others, the bill was vetoed by the Governor for fiscal reasons. This veto is unfortunate because local planning must be forced to deal with the negative effects of development on fighting wildfire. The Board plans to have the bill introduced again. So the second thing that you can do is to recognize the importance of strengthened local planning and to support such legislation. In addition, if such legislation passes, you can work locally to see that such planning is carried out. Even if a bill does not pass, you can press local government to address the cumulative effects of development on wildfire risk and control tactics.

Third, we must address the badly designed development patterns that give us narrow access roads, unsigned structures, and no reserve water supplies. It is a firefighter's nightmare to approach a wildfire and see a narrow curved road, with overhanging vegetation, and panicked residents driving out. What would you do? Fortunately, the Legislature passed and the Governor signed SB 1075 in 1987. This bill requires the Board to adopt minimum, <u>statewide</u> standards for access roads, street and structure identification, minimum private reserve water supplies, and fuel breaks and greenbelts. The requirements will apply to all structures constructed in State Responsibility Areas after July 1 of next year. The bill is not retroactive, but we believe that over time much of the problem of poor infrastructure will take care of itself as change means that the standards will apply. The Board has spent the last year developing draft regulations to implement the bill. This draft is now being circulated for public comment in advance of a more formal proposal being scheduled for hearing early next year. Thus the third thing that you can do is to get a copy of the draft and to support our adoption of strong minimum standards. Vigorous support for these standards makes it easier to deal with strong opposition.

And finally, a centralized data base is necessary for all of us to analyze the effects of more people moving into wildland areas. This is just as true for a subdivision as it is for a powerline, a dam, timber harvesting, or another project. Each agency seems to have its data base. But nowhere is our data drawn together at a common source or put in a common geographic information system that is readily accessible to decision makers or project planners. Nor is it collected by the same standards. The closest thing I know is the data base that led to the Forest Assessment that I showed you earlier. In our age of information sophistication, such a failing is shameful--despite all the proprietary and political reasons why each agency guards its information base and ways of collecting the information.

I know that an effort is in progress to develop a common geographic information system among state agencies. This effort as well as any other effort of a similar nature deserves your support.

It is almost anticlimactic to say again that the movement of people into the wildland areas is our key difficulty. We cannot stop this movement, and as a philosophic view I am not sure we should try. But we <u>can</u> do a better job managing the pressure of the wildland-urban interface. I have offered you some suggestions about wildfire. They all require an activist role, whether it be support for more vigorous enforcement of clearance laws, stronger general planning laws to deal with wildfire, tough minimum statewide standards for things like access roads and minimum water supplies, or a common and standardized data base. When you venture into the world of wildfire and watersheds, you definitely get flame that water will not put out. It is political flame caused by people wanting to live in rural California. I encourage you to blow on this flame so it does not burn us. Only by being active, within your agencies and at the local and state political level, can you blow hard enough.

Land Use Decisions & Fire Risk

Wildfire in the Pacific West: A Brief History and Implications for the Future[1]

James K. Agee

Abstract: Wildfire has been for millennia a natural component of our western forested wildlands. Its frequency, severity, and effects have varied depending on the specific environment, the type of fire, and the adaptations of the forest biota to fire. The socio-political environment in which these forests exist has had a much more significant impact on public and private policy towards fire than the physical-biological environment. Although ecological criteria are important in technical planning, they will be overshadowed by socio-political criteria in problem definition and solution for the future.

The Pacific coastal states (California, Oregon, and Washington) are fire environments, historically subjected to fires of myriad frequencies, intensities, and extents. These natural forest fire regimes have been significantly altered over the past 150 years, primarily in response to socio-political pressures that resulted in more or less fire than projected under a natural fire regime. This paper summarizes these natural fire regimes, the evolution of fire policy in these areas, and fire management implications for the near future.

THE NATURAL FOREST FIRE REGIMES OF THE PACIFIC WEST

The fire regime concept is one way to group potential ecological effects of fires. A fire regime is defined by patterns of similar fire frequency, intensity, and extent. It can be characterized by the environmental factors that determine plant growth (temperature and moisture patterns), ignition sources (lightning, human), and plant species characteristics (fuel accumulation, adaptations to fire) (Agee, in press (b)). The descriptions below apply to "unmanaged" or "natural" forests, but such "baseline" fire regimes have important implications for forests managed for single or multiple uses. Forest fire regimes of the West can be placed in one of three arbitrarily defined categories, which overlap considerably (fig. 1): high, moderate, and low severity, describing the ecological effects generated by the fire.

The high severity fire regimes are generally in cool and wet environments, with fire occurring under unusual conditions: drought and dry, hot winds (Pickford and others 1980). Fires may be of high severity but usually are of short duration (days to weeks). Crown fires and severe surface fires account for most area burned and usually kill all the trees in the stand. Fire return intervals range over 100 years and may not be cyclic (Hemstrom and Franklin 1982, Fahnestock and Agee 1983).

Moderate severity fire regimes typically occur in areas with extended summer drought, and individual fire durations are often weeks to months. The extended burning time is associated with a variety of burning conditions due to variable weather. The overall effect is a patchiness on the landscape as a whole, with individual stands often consisting of two or more age classes. The moderate severity fire regime can also be thought of as a combination of the high and low severity regimes, with each dominating as a function of site-specific fuels, weather, and topography. Dry Douglas-fir forests and red fir forests, with fire return intervals of 25 to 100 years, are examples of moderate severity fire regimes (Means 1982, Morrison and Swanson, in press, Pitcher 1987).

In low severity fire regimes, natural fires are typically frequent (<25 years apart) and widespread. With limited time for fuel to accumulate, fires are of low intensity, which the dominant trees are adapted to resist. Ponderosa pine forests and oak woodlands are examples of low severity fire regimes (Wilkes 1844, Biswell and others 1973, Bork 1985).

DEVELOPMENT OF FIRE POLICY

Natural criteria, such as the historical role of fire in ecosystems, have been secondary to social criteria in directing fire management policy for western forests. In low severity fire regimes, where fire was frequent, social forces did not allow for controlled use of fire, while in high severity fire regimes, where fire was infrequent, controlled use of fire for slash burning was tolerated and to some extent mandated. These patterns are a result of people's response to fire as a threat (Lee 1977).

The Need for Management

At the turn of the 20th century, fire control as a forest policy was in its infancy. Fires set purposely or accidentally by humans were common. In Oregon and Washington, disastrous regional fires in the summer of 1902 occurred in nearly

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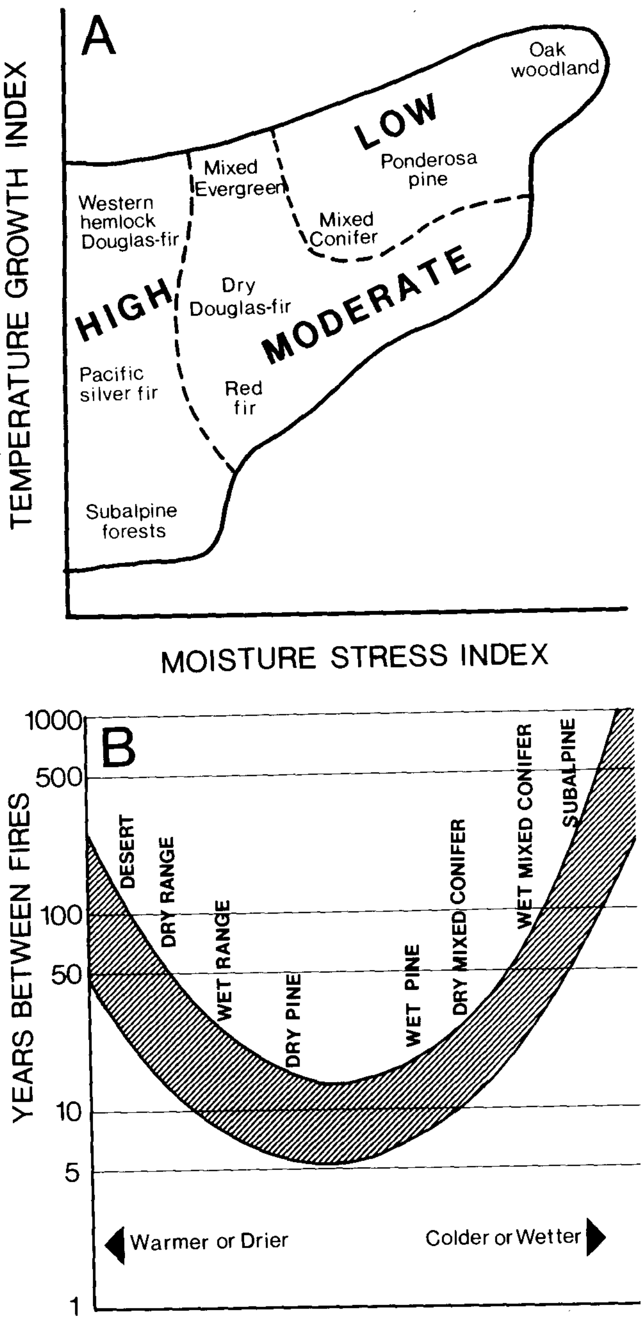

Figure 1--A: Fire regimes are defined by fire patterns: various forest types can be described in terms of the severity resulting from fires of various frequencies and intensities (Agee in press (b)). B: Environmental conditions can be associated with fire return intervals in a variety of landscapes of the West (adapted from Martin 1982).

every county west of the Cascades in Oregon and Washington (McDaniels 1939). Fire control organizations began to appear in these states and California (Allen 1911, Clar 1969a). Foresters believed that before forest management could become effective, control over forest fire, particularly underburning, was imperative (Steen 1976).

Evolution of Fire Management Policy

In the high severity fire regimes of the Pacific Northwest, industrial landowners led the way towards more effective fire protection. At the same time, they felt that burning slash fuel on cutover areas would better protect the virgin timber supply. Slash burning was recognized as a legitimate forest management tool, particularly since it was done on land whose immediate value was very low.

Slash burning in the Douglas-fir region evolved from a policy of spring or fall burning, which was adopted after 1910 (Allen 1912) to almost exclusive fall burning after some serious fire escapes, including over 100,000 acres (40,000 ha) in 1922 (Joy 1922). Research on slash burning (Hofmann 1922, 1924) highlighted both positive and negative impacts, but the practicality of mandatory slash burning began to be questioned. A debate at the Pacific Logging Congress of 1925 suggested that cutover areas, once spaced far apart, were now contiguous for 10 to 30 miles, and that slash fires repeatedly overran such areas, killing regeneration (Lamb 1925). "Blanket rules" for mandatory slash burning were criticized (Allen 1925). Nevertheless, due to liability laws, slash was burned on most cutover areas up into the 1960's (Agee, in press (a)).

The use of fire in the infrequent but high intensity fire regimes of the Pacific Northwest contrasted with the approach adopted in California in low severity fire regimes, where frequent surface fires had burned through the mixed conifer forests for centuries. The use of underburning in merchantable stands was seen as a continuation of Indian burning practices, and "Piute forestry", as light burning practices were called, was perceived as a threat to forest management (Pyne 1982) and a "challenge to the whole system of efficient fire protection" (Graves 1920).

In 1910, the debate over the practicability of light burning in pine forests began with an article promoting the use of underburning (Hoxie 1910). Foresters replied by showing the detrimental impact of fire on seedlings and saplings, even though residual stands were well stocked (Pratt 1911), and contrasted "promiscuous" light burning with slash burning of the Pacific Northwest, which was "...never allowed to run at random; it is systematically set out, and controlled absolutely" (Boerker 1912). At the time, however, slashing fires were still a major cause of wildfires in the Northwest (Elliott 1911).

In California, the debate on light burning continued into the early 1920's (Graves 1920, Show 1920, White 1920). At the time, fire control in these pine forests was relatively easy; forest rangers tied branches onto their horses' tails and walked them through the forest, scattering pine needles from the path of the oncoming low flames (Munger 1917). In the 1920's, the light burning controversy was reviewed by a commission which noted that practicality, not theory, was the issue, and that full protection appeared to be more practical and economical (Bruce 1923). The classic bulletin against light burning (Show and Kotok 1924) lumped effects of summer wildfires with lighter spring or fall burning; by 1928, the light burning controversy had died down (Clar 1969b), but it was to resurface decades later.

Policy Reevaluations

By the mid-1950's, reevaluation of fire as a threat eventually resulted in relatively less slash burning in high severity fire regimes and more underburning in low severity regimes. Foresters in the Douglas-fir region began to doubt the need for compulsory slash burning in the early 1950's, comparing the practice to committing suicide for fear of incurring an accident (Hagenstein 1951). Forest Service research had indicated generally negative impacts from slash burning (Isaac 1930, Isaac and Hopkins 1937) except for hazard reduction (McArdle 1930, Munger and Matthews 1939). Even now, there is limited evidence that prescribed fire west of the Cascades reduces the threat and costs of destructive wildfire (Deeming, in press). In a reaction to environmental concerns about smoke, burning seasons were expanded into the wetter months during the late 1960's (Dell 1969). Complex manuals were developed to predict environmental effects (Cramer 1974). Air quality legislation and regulation over the last 10 years (Clean Air Act Amendments of 1977, PM10 regulations for fine particulate) suggest that slash burning, as well as other uses of fire, will be restricted increasingly in years to come.

In the low severity fire regimes of the eastern Cascades and California, researchers began to provide evidence that a "blanket rule" forbidding fire use in these areas had contributed to increased insect problems, increases in fuel hazards, and undesirable species composition changes (Weaver 1943, Biswell and others 1955). Wildfire effects in these historically low severity fire regimes were beginning to mimic those of high severity fire regimes, as all but the most severe fires were being contained. Light burning resurfaced when the Department of the Interior accepted the Leopold Report (Leopold and others 1963), a wildlife commission report which recognized the important role such fires played in National Park ecosystems. The emergence of other groups in society advocating use of fire as a tool (environmental preservationists, hunting clubs, gravel mining interests) helped to institutionalize the use of fire as a tool (Lee 1977). The application of prescribed and natural fire in national park ecosystems (Kilgore 1976) and broader use for hazard reduction and wildlife management is now widely accepted by both professionals and the public.

IMPLICATIONS FOR THE FUTURE

People have traditionally viewed wildfire as a threat or a problem rather than an ecological event (Lee 1977). In high severity fire regimes, this threat was dealt with by using fire as a hazard reduction tool after logging. In low severity fire regimes, the "promiscuous" threat was mitigated by removing fire from the ecosystem to the extent possible. Both ecological and social changes have occurred in these fire regimes, with a concomitant redefinition of threats. If the historical paradigm of fire policy reacting to threat continues, some implications for the future can be projected.

High Severity Fire Regimes

Fire is typically an infrequent event in ecosystems with high severity fire regimes, and fire control has been relatively effective. The threat of air pollution in the populated western parts of Oregon and Washington is likely to overshadow the benefits of hazard reduction, and slash burning may tend to become even more restrictive (Agee, in press (a)), in terms of both area burned and emissions per unit area burned (Sandberg 1987). In the future, programs to expand the natural role of fire in wilderness may be the most significant trend. Most of the park and wilderness fire programs are new and have not dealt with a major fire, as such events are infrequent. The 900,000 acre (385,000 ha) fire episode in Yellowstone in 1988 may generate some changes in current policy towards more prescribed burning rather than the use of natural ignitions to accomplish natural area objectives. Support by environmental groups for wilderness fire may waver if smoke or flames from large fires penetrate urban or rural residential areas, which are already becoming sensitive to wood smoke from stoves (Koenig and others 1988). Without forest industry, residential, or environmental group support, wilderness fire policies may evolve to more restrictive and prescriptive rules.

Moderate Severity Fire Regimes

In moderate fire regimes, where fire control is exercised, the average fire may be more severe than in the past, since the only fires that spread do so under severe burning conditions.

The buildup of fuel hazards in these areas occasionally results in large, uncontrollable fires, such as the southern Oregon fires of 1987. This overwhelming of fire control capability has led to a wider range of fire severity and probably more landscape diversity than is usual for smaller fires, where control is possible as soon as severe fire weather ceases.

The moderate fire severity regimes provide the most difficult management problems. The threat of air pollution from hazard reduction will be balanced against the threat of wildfire if hazard reduction is not undertaken. Potential for fuel manipulation through underburning is moderate to low, because of generally narrow prescription windows. Use of prescribed fires is hampered both by low rates of spread under damp conditions and by potentially high rates of spread and intensity under dry conditions.

The large wildfire years, such as 1987 and 1988 in the West, will encourage innovative fuel treatments, but in several years' time the threat of such fires will have dimmed in the public eye, while anxiety about potential prescribed fire control and smoke problems will be freshly renewed each season.

Low Severity Fire Regimes

In low severity fire regimes, forests once subjected to frequent, low severity fires now have less frequent but higher severity fires, such as occurred in the central Sierra Nevada in 1987 and 1988. A computer simulation of historical fire incidence and behavior (van Wagtendonk 1985; fig. 2A) indicates that frequent fires kept potential energy at low levels on the forest floor, whereas with successful fire exclusion potential energy increases and remains high over time. Wildfire occurrence under the latter conditions results in high intensity fires. Prescribed fires (fig. 2B) can be used to reduce this potential energy slowly back to lower, safer levels. In the Pacific Northwest pine-larch-fir type, understory burning is now being implemented on more than 9,000 acres (3600 ha) per year on National Forests of that region (Kilgore and Curtis 1987), but this area is only 0.7 percent of the type. The trend is promising but insufficient at present to combat fuel hazard buildups.

Unfortunately, the 80 years of fuel buildups we have allowed is analogous to deficit spending. The initial political decision to implement a policy of total fire suppression was justified by fire protection costs of the day, which were relatively low in the sparse fuel conditions of those forests. Today's accumulation of fuel can be translated into potential air pollution to be created if it is burned. Undoubtedly, this issue, like those of the past, will be resolved by a social decision on which is the greater threat: wildfire or air pollution.

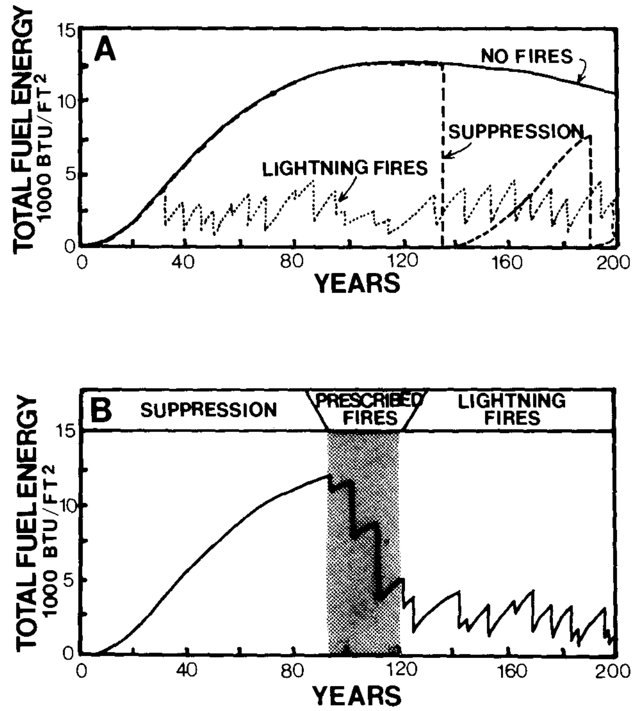

Figure 2---Computer simulation of fuel energy buildup and reduction with FYRCYCL computer program. A: Total fuel energy accumulation under three fire scenarios: Lightning Fires, where the natural role of fire is dominant, No Fires, where all fire is successfully suppressed, and Suppression, where only fires with crown fire potential escape control. B: Management of fuel energy through prescribed fire during the middle period (shaded area) after which lightning fires are allowed to burn (van Wagtendonk 1985). Continuation of prescribed fires beyond the shaded period is another option.

Balancing the Threats

My prognosis is that air pollution will be perceived as a greater threat than wildfire hazard in the coming decade for two reasons: (1) institutions are better organized to deal with air quality, and (2) prescribed fire that creates pollution is more likely to affect more people more often than wildfire, albeit in different ways. Air quality regulatory agencies are well established, and have as goals reduction of air pollution from managed activities. Land management agencies have a less focused, broader mandate, including the balancing of smoke impacts from wild and prescribed fire (assuming that to some extent use of prescribed fire can reduce wildfire smoke occurrence). As well as being quantitatively difficult to balance, control and use of fire are often funded differently. Fuel treatment costs are billed to operating funds, while savings in wildfire suppression costs from such treatment are not counted as a benefit (e.g., Agee 1984), making treatment difficult to justify operationally.

As rural development creates a constituency for reduction of wildfire hazard for structural protection, the air pollution threat may be overwhelmed by the wildfire threat. However, because prescribed underburning will be creating smoke annually, contrasted to less frequent wildfire disasters, fuel treatment may depend on recurring disasters in order to remain socially acceptable. Even in communities recently affected by wildfire, disaster creates complacency: a perception that either lightning doesn't strike twice (Burton and Kates 1964) or that future vulnerability to fire is reduced by the recent disaster (Gardner and others 1987). Recognition of the social factors driving fire policy and the need for education will help land management professionals understand and influence future policy.

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Use of Prescribed Fire to Reduce Wildfire Potential[1]

Robert E. Martin, J. Boone Kauffman, and Joan D. Landsberg[2]

Abstract: Fires were a part of our wildlands prehistorically. Prescribed burning reduces fire hazard and potential fire behavior primarily by reducing fuel quantity and continuity. Fuel continuity should be considered on the micro scale within stands, the mid-scale among, and the macro-scale among watersheds or entire forests. Prescribed fire is only one of the tools which can be used to reduce fire hazard, but it can be effective at all scales.

Fire has been a part of many ecosystems, playing a large role in shaping them and leading to the adaptations of many plants and animals to different fire regimes. Without fires, many of the vegetative types and the associated fauna have changed drastically. The type may have become susceptible to changes from biotic or abiotic agents, and may lose its desirable characteristics for many years.

Removal of fire from many of our forest and range types has led to change in species composition and accumulation of excessive biomass; it has set the stage for high-intensity, high-fuel-consumption, stand-removal fires. The purpose of this paper is to discuss the use of prescribed fire to reduce the potential for such fires.

It should be noted that prescribed fires generally also accomplish other land management goals. These include maintenance of stand composition, increase in water quantity and quality, reduction of insect or disease damage, and increase in esthetic and recreation value. Few prescribed fires could accomplish all of these objectives, but most, when well planned and executed, could accomplish several of them. Today, with our limited operating dollars, multi-objective prescribed fires are the rule rather than the exception.

Prescribed fire is only one way to reduce wildfire potential. Fuels management, which is that branch of fire management dealing with the fuels, begins with vegetation management. Thus, the right vegetation in the right place is the first step in reducing wildfire potential. Biological, chemical, manual, and mechanical means may be used in conjunction with fire to modify fuels. The total job of managing fuels - fuels management - is the art or practice of controlling the flammability and resistance to control of wildland fuels through the means described above in support of land management objectives (Lyon 1984).

Reduction of wildfire potential is best described in terms of modifying potential fire behavior. In turn, fire behavior is influenced by the three elements of the fire behavior triangle--fuels, weather, and topography. Of the three, the only one we can easily and directly affect is fuel, the biomass, or more specifically, the phytomass. We will first describe the basic properties of fuels which are important to fire behavior and then look at what prescribed fires can do to fuels, and how this reduces the potential for large wildfires and increases our ability to control them.

BASIC CHARACTERISTICS OF FUELS

Fuels can be described by six basic characteristics, and these characteristics (Martin and others 1979) are chemistry, particle and density, moisture content, compactness, continuity, and quantity. Only the last two, continuity and quantity, are discussed in this paper, as they are most affected by prescribed burning.

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Continuity

Continuity expresses the degree or extent of continuous distribution of fuel particles in a fuel bed (or over the landscape). The parentheses indicate a broader concept of the definition, which I am adding. Continuity affects a fire's ability to sustain combustion and spread (Lyon 1984).

Continuity is important both horizontally and vertically. Surface fires need horizontal continuity to spread unless they can spot by embers dropped ahead of the fire into other fuels. Vertical continuity allows fire to move upward, most notably into the crowns of tall shrubs or trees. When fire moves into tree crowns, spotting distance for embers increases greatly, and fires become more uncontrollable. When one or a few tree crowns burn, we often refer to the phenomenon as torching, whereas when the fire continues to spread in the crowns, we would call it a crown fire.

As compared to other characteristics of fuels, continuity is difficult to measure in ways meaningful to fire spread. In large measure, this is because gaps in fuels have more or less significance depending on the nature of the fire.

Quantity

The amount of fuel per unit of area is an obvious characteristic of fuels in influencing fire behavior. Quantity is generally expressed in tons per hectare or tons per acre, but is also given in units of kilograms per square meter or pounds per square foot. The quantity of fuel must also express whether the fuel is live or dead, herbaceous or woody, and its size class.

REDUCTION OF WILDFIRE POTENTIAL

Prescribed fire affects fire potential primarily by modifying the continuity and quantity of fuels. These characteristics may be changed on a microscale within stands, on a midscale among stands, or on a macroscale throughout an entire forest or watershed.

Both horizontal and vertical continuity are reduced for a period after a burn. The horizontal continuity returns more rapidly, as trees put down more needles and branches. However,

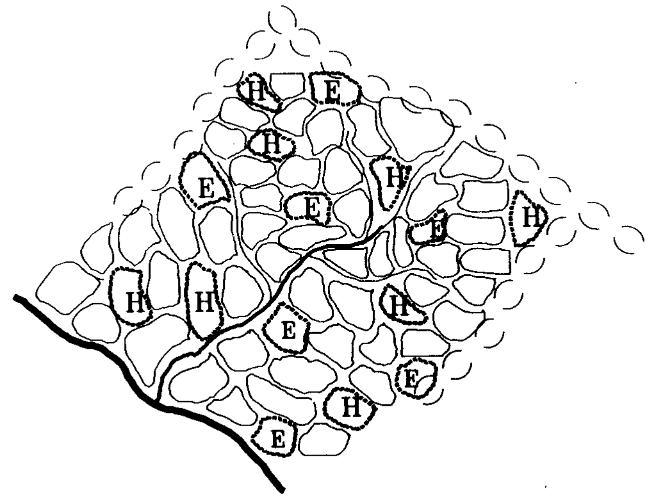

Figure 1.- The pattern of arrangement of high and extreme fire hazard and resistance to control among units of low and medium hazard is the key to reducing wildfire potential at the midscale.

vertical continuity is interrupted for a long period of time, sometimes until the end of stand rotation. Shrubs and understory trees may tend to restore vertical continuity, but the pruning effect of fire on the lower branches of trees will permanently move the crown fuels higher and thus less reachable by surface fires.

Continuity of fuels on a larger scale is also reduced. Within a small drainage, areas of high or extreme fire hazard may be isolated by burning of intervening stands. Seedling and sapling stands generally have crowns which are close to the surface and contiguous with surface fuels. Further, the young stands may be too sensitive to fire to use prescribed burning to reduce fuels there. It would then be important to isolate these stands in such a way as to reduce the potential for wildfire to spread from one to the other (fig. 1).

In fighting a fire, the decision may be not to fight the fire within the high or extreme hazard area but to keep it from spreading into adjacent units. Since only about 20 percent of a stand's rotation time is in the seedling and sapling stage, only about the same percentage of the total forest area would be in this stage. The individual units could be isolated, effectively reducing continuity on the midscale.

Fuel continuity can also be reduced on the macroscale by isolating various

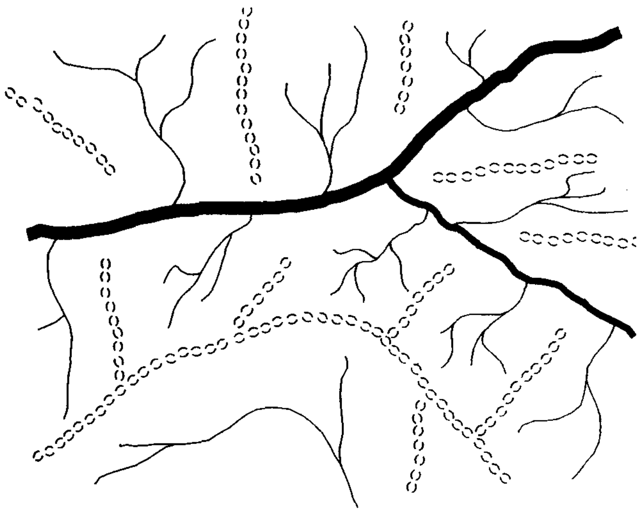

Figure 2.- Reducing continuity on the macroscale can be important in preventing fire spread from watershed to watershed or across a large segment of a forest.

parts of a forest or range by fuel modification areas. I don't use the term fuelbreaks here because these are defined very specifically and are often not effective in stopping high intensity headfires. Fuelbreaks, that is, fuel modification areas 100 to 300 feet wide, may be the beginning of effective fuel modification areas by serving, for example, as the backdrop against which prescribed burning can be done.

Modifying of fuel continuity on the macroscale would use terrain features and roads to isolate drainages from one another (fig. 2). Fuel modification areas follow ridges and streams as well as roads or other human artifacts. The fuels along ridges may already be reduced by rock outcrops or high elevation meadows. Where forests are present, the ridges may represent the lowest quality sites, so reduction in timber growth there to protect the forest would have the least effect on total production.

Areas along streams may be more moist or contain less flammable vegetation, providing a first step in developing a fuel modification area. Where stream bottoms are broad and in meadows or areas dominated by low flammability species, very little additional work may be needed.

In planning prescribed fires, it should be pointed out that reducing fuel continuity on the mid- and macroscale may not be effective if fuel continuity and quantity are not reduced within stands, as exemplified in the 1987 fire experience. Extreme fire weather and long distance spotting combine to overwhelm fire fighting organizations unless fuel modification has been done within individual stands.

EXAMPLES OF EFFECTS OF PRESCRIBED FIRE ON WILDFIRE POTENTIAL

To illustrate how prescribed fire reduces wildfire potential within stands primarily through reducing fuel continuity and quantity, I'll use prescribed fire sites in Washington, Oregon, and California (fig. 3). The sites vary considerably from each other. However, wildfires occurred in the same or similar stands, giving us the opportunity to compare wildfire behavior in unburned and burned stands. Additional replication is needed before this case study is extrapolated to other locales, although many fire managers and researchers have noted similar fire potential reduction by prescribed fire.

The stands have a wide range of characteristics and histories (Table 1). The Coyote Creek plots were burned three times by Harold Weaver, starting with thickets of pine seedlings (Weaver 1957). The results of his thinning with fire resulted in stands similar to those represented by the hand-thinned stands on the Kelsey and Lava Butte sites, which were burned in the late 1970's. The Lookout and Walker Mountain sites are older pine stands, and the Challenge and Blodgett sites are mixed conifer stands.

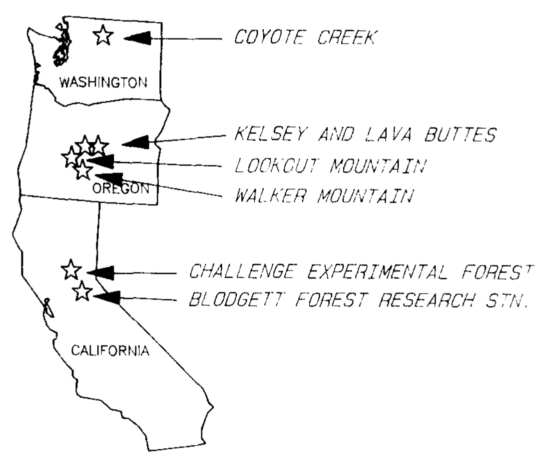

Figure 3.- Units used as examples for reduction of fire potential by prescribed burning are from Washington, Oregon, and California.

Table 1--Characteristics of the sites from which the effects of prescribed burning on wildfire potential were estimated.

Site Feature	Site: Coyote Creek	Kelsey Butte	Lava Butte	Lookout/ Walker	Challenge/ Blodgett
Type	Ponderosa pine Shrub Pine Grass	Ponderosa pine *Ceanothus velutinus* *Arctostaphylos patula*	Ponderosa pine *Purshia tridentata*	Ponderosa pine *Ceanothus velutinus* Hardwood Grass	Mixed conifer Hardwood *Ceanothus integerrimus* *Arctostaphylos patula*
Locale	N.C.WN	C. OR	C. OR	C. OR	N. CA
Site	Low	Low	Low	Medium	High
Quality	3 & 4	3 & 4	3 & 4	2	1
Age	60	70	70	150	65
Burned	1942-67	1978	1979	1976-82	1983-84

The differences between the stands point up the possibilities for multiple-fire prescribed burn programs that could reduce hazard and prevent potentially dangerous wildfires. Units are discussed in order from north to south.

Coyote Creek

This area was burned in 1942, 1954, and 1967 by Harold Weaver of the Bureau of Indian Affairs. The burn and control plots were pine thickets, and for the first burn were all less than 5 feet high, as indicated in photographs. Today, ponderosa pine on the burn plots ranges in diameter from 4 to 8 inches, whereas the unburned plots remain as stagnated thickets with stems from about 1 to 4 inches in diameter.

The burned plots have an effective break in vertical continuity with an understory of pinegrass and some shrubs, mostly a wild rose. Wildfires under moderate conditions would do no damage in the stand, and under extreme conditions would do little damage and be easy to control. In the unburned plots, wildfire under any conditions would torch almost all the crowns and present control and spotting problems. The entire stand would be destroyed. In addition to the benefits to tree growth and fire management, the burned stands provide grazing not available in the unburned stands.

The burned stands need further thinning by hand to obtain more ideal spacing and to remove those trees which were scarred during the burning operations.

Kelsey Butte

These plots were burned only once under very moderate conditions because of the high fuel loads, the shrub understory, and the low crowns. The stands had been thinned 8 to 10 years before burning, and the thinning slash persisted in the dry Central Oregon climate. The first burn was designed to reduce the fine fuels and to reduce the vertical fuel continuity, with the idea that the second and third burns would be needed to make the stands reasonably firesafe.

A wildfire ran into the stands before followup burns could be conducted. In the unburned stands, the wildfire torched out most trees and continued to move unchecked. In the burned stands, the fire dropped to the ground with only an occasional tree torching out. The burned plots were used to control one flank of the fire, and a small percentage of the trees survived.

Increment borings of burned and unburned stands indicated no effects on growth from the prescribed burns.

Lava Butte

The Lava Butte plots were burned to study the effects of prescribed burning on nutrients, understory vegetation, and ponderosa pine growth (Landsberg and others 1984). About half were burned for high fuel consumption, removing 80 percent or more of the down and dead fuels and of the litter (01) and duff (02 and 03 layers) . The moderate fuel consumption burns consumed around half the fuels, although the results were variable.

Based on observed fire behavior in other areas, the high fuel consumption units could probably survive a wildfire under extreme conditions with moderate damage and almost no torching of trees. Under moderate conditions a wildfire would have little effect on the stand. In contrast, the moderate consumption units would involve some torching and fairly high crown scorch under extreme wildfire conditions, but only moderate damage would occur under moderate wildfire conditions. The unburned controls would be mostly destroyed under both moderate and extreme wildfire conditions, and with many trees torching, spotting, and presenting difficult control problems.

The stands which received moderate and high fuel consumption prescribed burning treatments demonstrated 4 and 20 percent growth reductions in comparison to the unburned control in the first 4 years following burning (Landsberg and others 1984). The duration of the growth differentials is unknown.

Lookout and Walker Mountains

These sites are quite similar and will be covered together. They are older stands on sites which are quite good for Central Oregon ponderosa pine. They are even-aged, probably originating after wildfire. Since they are better sites and higher in elevation, Indian and lightning fires occurred less frequently than on the lower sites, thus allowing for a greater probability of fuel accumulation and of stand-replacement fires.

Fuels reduction by all prescribed burns reduced fuel loads and continuities to the extent that wildfires would do low to moderate damage, depending on conditions, and present only moderate resistance to control. Without prescribed burning, wildfires under moderate conditions would scorch greater than 50 to 100 percent of the crowns of most trees but present only moderate resistance to control. Under extreme wildfire conditions, crown scorch would be high in all cases, and perhaps up to one-third of the crowns would torch, making control problems more difficult.

Blodgett and Challenge Sites

These are high quality sites, and even though there are differences between them, they are similar in fuel characteristics. Prescribed burning was conducted once or twice to reduce stored shrub seed in the soil and duff and to kill established shrubs and hardwoods, with the aim of reducing competition with a new stand (Kauffman 1987, Kauffman and Martin 1987). The first burns were designed to accomplish either moderate or high duff consumption, whereas the second burns were designed for high fuel consumption.

The stands are of mixed age, and all first burns reduced wildfire potential. On the moderate consumption burn sites, wildfires would be more likely to do stand damage and to torch out crowns with the attendant spotting. High consumption burns and the second burns would lead to successively less wildfire damage and potential fire behavior. In contrast, potential fire behavior on the unburned control would lead to extensive torching and spotting and thus high resistance to control. The 1987 wildfires in California are illustrative of the difficulty in controlling fires in this type.

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The Effects of Prescribed Burning on Fire Hazard in the Chaparral: Toward a New Conceptual Synthesis[1]

Anthony T. Dunn[2]

Abstract: Prescribed burning for fire hazard reduction in the chaparral is predicated on the belief that young fuels (20 years old and less) are highly resistant to burning. To test this belief, a data base search of large fires in San Diego County between 1940 and 1985 was conducted to locate reburns of young chaparral fuels greater than 1000 acres (400 ha) in extent. Of the 147 fires examined, 17 (11.6 percent) contained at least one area of young fuels that had reburned. The majority of the reburns occurred under severe weather conditions. The finding that young fuels do not necessarily inhibit the spread of large wildfires may have a potentially significant impact on future fuel management planning and prescribed burning policy.

Prescribed burning has become an accepted, economical, and widely used management tool for the reduction of fire hazard. First practiced extensively in the southern pine forests, use of prescribed burning spread to the pine forests of California where it was found to be effective in reducing heavy fuel loading (Biswell 1977). Beginning in the 1940's, the California Department of Forestry (CDF) began applying prescribed burning to the chaparral with the hope of reducing the occurrence of conflagration fires. In the 1970's the U.S. Forest Service (USFS) joined the CDF with its own chaparral prescribed burning program.

Despite the clear success of prescribed burning in forest communities, there is a growing concern among conservationists, researchers, and managers that the practice is not as effective in chaparral and does not always provide the advertised benefit of reducing fire hazard (Harrell and others 1987). This paper reexamines (from a fire history viewpoint) the major premise upon which prescribed burning policy in the chaparral is based, and provides information that may be helpful in evaluating the effects of prescribed burning on the chaparral and the role it should play in fire management.

[1]Presented at the Symposium on Fire and Watershed Management, October 26-28, 1988, Sacramento, California.

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CONCEPTUAL BASIS OF CURRENT POLICIES

Essentially, current policies governing prescribed burning for fire hazard reduction in chaparral can be traced back to a single major premise: that young fuels "are among the least flammable of all native vegetation phases" (State of California 1981). This premise is based on the belief that young chaparral fuels (20 years old and less) have lower fuel loadings and lower levels of dead fuels than older stands. Particularly important to prescribed burning policy is the role that dead fuels play in chaparral flammability. Live fuels are much less flammable than dead fuels, and without a large dead fuel component, chaparral is believed to be extremely resistant to burning (Green 1981). As the chaparral ages, it is assumed to accumulate approximately 1 percent of dead fuels (as a proportion of total biomass) per year (Green 1981, Rothermel and Philpot 1973).

Accordingly, the uniform stands of old brush that are believed to have arisen with the advent of fire suppression, with their high levels of extremely flammable dead fuels, are understood to represent an unnatural and highly flammable community that will generate ever larger and more catastrophic wildfires (Dodge 1972, Minnich 1983). Burning these stands is intended to restore the "natural" environment of frequent small fires and gives rise to a mosaic of fuel ages that inhibits the spread of large fires (Minnich 1983, Philpot 1974, Philpot 1977).

However, new research is beginning to challenge these widely held views. Work conducted at the USDA Forest Service Forest Fire Laboratory in Riverside, Calif. has demonstrated that live chaparral fuels are capable of supporting a propagating flame in the absence of any dead fuel component (Cohen and Bradshaw 1986). Demographic studies of older chaparral fuels have shown that these stands, far from being "decadent" or "senescent," are often quite healthy and vigorous (Montegierd-Loyba and Keeley 1986). Preliminary measurement of the characteristics of older chaparral fuels suggests that levels of dead fuels are not directly related to age (Anderson and others, 1987), and may not show significant changes over extended periods of time (fig. 1)

FIRES IN YOUNG FUELS: A FIRE HISTORY PERSPECTIVE

If young fuels are indeed highly resistant to burning, then instances where large acreages of young fuels burn should be rare. In order to test this belief, a data base search of large fires in San Diego County was conducted using original fire maps compiled by Dunn (1987). In addition, relevant examples of fires occurring outside of San Diego County have been included in the discussion. For the purpose of this paper, "large fires" are those 300 acres (120 ha) and greater. Though these fires account for only about 1 percent of all wildfires, they consume about 70 percent of the acreage burned (State of California 1983, 1984).

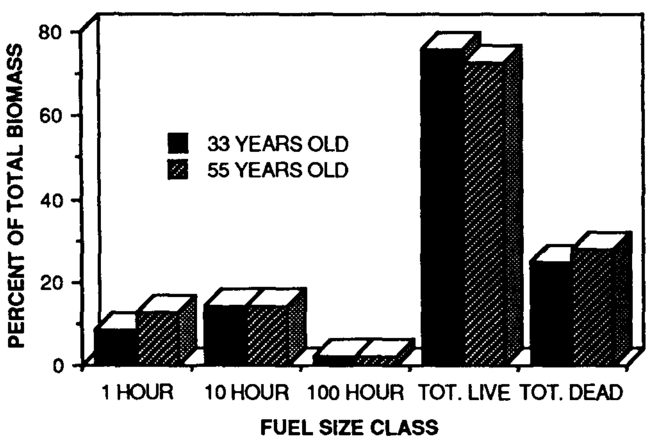

Figure 1--Fuel characteristics of chamise (*Adenostema fasciculatum*) at the North Mountain Experimental Forest. Data for 33-year-old fuels (sampled 1964-65) from Countryman and Philpot (1970); data for 55-year-old fuels (sampled 1986) on file, Forest Fire Laboratory, Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, Riverside, Calif.

Study Location and Methods

The nondesert area of San Diego County covers approximately 1,574,000 acres (629,600 ha), not including the 'nearly 500,000 acres (200,000 ha) of urban and agricultural areas within the county. The climate of the area is typically Mediterranean, with cool, wet winters and extended summer drought. Elevations range from sea level to over 6500 feet (1980 m), with precipitation levels generally following elevation; from 10 inches (250 mm) on the coast to over 40 inches (1000 mm) in the Palomar Mountains (Krausmann 1981). Vegetation varies greatly over short distances, but generally follows rainfall and temperature gradients, with coastal scrub on the coastal mesas, chamise and mixed chaparral in the foothills and backcountry ares, oak woodland in valleys and at higher elevations, and mixed conifer forests above about 5000 feet (1500 m) (Beauchamp 1986). Chaparral associations are far and away the most prevalent type of vegetation, covering nearly a million acres (400, 000 ha).

Original fire reports and perimeter maps were collected for all large fires in San Diego County for the period of 1910-85. Since the vast majority of backcountry areas in the county fall under either USFS or CDF protection, these agencies were the primary sources of fire history information. Copies of the original fire reports for the Cleveland National Forest were obtained from the Emergency Command Center in El Cajon. Original fire reports kept by the CDF were obtained both from the CDF Fire Prevention Office in Sacramento and from the Monte Vista Ranger Unit in El Cajon. Aerial photos were also used in a number .instances to either provide maps of fires for which none could be found or to confirm the extent of fires where the existing maps were of questionable quality. In all, 548 verifiable large fires were identified in San Diego County between 1910 and 1985, for a total of 1,751,231 acres (700,492 ha) consumed in all fuel types.

The data base search was set up to locate reburns of young chaparral fuels using the following criteria: (1) reburns must have occurred no earlier than 1940; (2) reburned areas must be 1000 acres (400 ha) or larger; (3) the period between fires must be 20 years or less; and (4) fuel types must be primarily chaparral.[3]

The criteria for reburns was set at 1000 acres (400 ha) in order to minimize the potential effect of poorly defined fire perimeters. There were numerous instances of smaller reburned areas, including fires of 300-999 acres (120-400 ha) occurring entirely within the perimeters of larger fires; these were not included in the analysis. Only fires from 1940 onward were included in the search, because older fire maps were often less reliable than those after 1940. The extent of one fire included in the search (the 1970 Laguna fire) was verified by large-scale aerial photographs taken shortly after the fire.[4] Areas consumed by reburns were calculated using a Tectronix digitizer.

<u>Study Results and Discussion</u>

Since the lower limit for area reburned was defined as 1000 acres (400 ha), only fires of that extent and larger were included in the search. In the period of 1940-85 there were 147 fires in

[3] Vegetation type data was obtained from USDA Forest Service (1934, 1969) and from unpublished 1934 Vegetation Type Map survey field maps on file at the Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, Berkeley, Calif.

[4] Photographs on file, San Diego County Department of Public Works, Survey Records Division, San Diego, Calif.

Table 1.--Reburns of young chaparral fuels in San Diego County. Fuel types are as follows: 1) chamise chaparral; 2) mixed chaparral; 3) oak woodland; 4) coastal scrub.

FIRE NAME	DATE	TOTAL ACREAGE	(HA)	ACREAGE REBURNED	(HA)	FUEL AGE	FUEL TYPE[1]	GENERAL WEATHER[2]
Hauser Mt.	7/12/1940	7000	(2800)	1820	(728)	15	1,2	SW Flow
El Cajon Mt.	7/7/1942	2963	(1185)	2030	(810)	13	1,4	SW Flow
West Hauser	8/22/1942	4100	(1640)	1540	(615)	17	1,2	SW Flow
Potrero	9/22/1943	3200	(1280)	1760	(700)	15	1	?
Miner	8/27/1944	[3]43520	(17410)	23400	(9360)	16	1,2	SW Flow?
Morales	10/24/1945	5500	(2200)	3950	(1580)	16	1,3	Santa Ana
Harper	7/1/1947	17390	(6960)	1180	(470)	6	2	SW Flow?
Glencliff	9/3/1948	1630	(650)	1260	(500)	20	1	?
Conejos	8/16/1950	63406	(25360)	4140	(1655)	16	1	SW Flow?
Bronco Flats	10/4/1953	9250	(3700)	1540	(615)	5	2	Santa Ana
Bronco Flats	10/4/1953	9250	(3700)	6980	(2790)	10	1	Santa Ana
Pine Mt.	9/8//1956	6970	(2790)	1000	(400)	6	1	NW Flow?
Inaja	11/24/1956	43904	(17560)	1130	(450)	13	1	Santa Ana
Chocolate	9/6/1957	3890	(1555)	1345	(540)	7	1,2	SW Flow
Woodson	10/30/1967	30000	(12000)	1840	(735)	9	1	Santa Ana
Pine Hills	10/30/1967	7030	(2810)	3190	(1275)	11	1,2,3	Santa Ana
Laguna	9/26/1970	175420	(70170)	6930	(2772)	17	1	Santa Ana
Laguna	9/26/1970	175420	(70170)	1235	(495)	17	4,1	Santa Ana
Laguna	9/26/1970	175420	(70170)	1080	(430)	18	1	Santa Ana
Laguna	9/26/1970	175420	(70170)	2150	(860)	20	1,4	Santa Ana
Laguna	9/26/1970	175420	(70170)	1200	(480)	20	4,1	Santa Ana
Laguna	9/26/1970	175420	(70170)	5300	(2120)	20	4,1	Santa Ana
Miller	6/30/1970	8000	(3200)	4120	(1650)	15	1,4	SW Flow

[1] Fuel types listed in order of prevalence.

[2] Actual synoptic weather types are often difficult to determine without upper air data. General weather influences were estimated based on the general direction of spread of the fires.

[3] 28,160 acres (11,264 ha) in San Diego County.

San Diego County in this size range. These fires accounted for 45.9 percent of all large fires and 92.3 percent of the acreage consumed by large fires. (Though no actual comparison was made, it is estimated that these 147 fires accounted for approximately 0.5 percent of the fires in all size classes and consumed approximately 65 percent of the total acreage burned in the county during this period.) Of this total, the search turned up 23 instances of reburned chaparral fuels in 17 fires (table 1). Thus, 11.6 percent of all fires greater than 1000 acres (400 ha) burned more than 1000 or more acres of young chaparral fuels. These 17 fires burned a total of nearly 418,000 acres (167,000 ha), or roughly 25 percent of the acreage consumed by all fires in the county between 1940 and 1985. The 1970 Laguna fire alone burned through six separate areas of young fuels greater than 1000 acres (400 ha) in extent, plus a number of smaller areas of young fuels. All told, the Laguna fire burned over 26,000 acres (10,400 ha) of fuels 20 years old or less, about 15 percent of its total area (fig. 2).

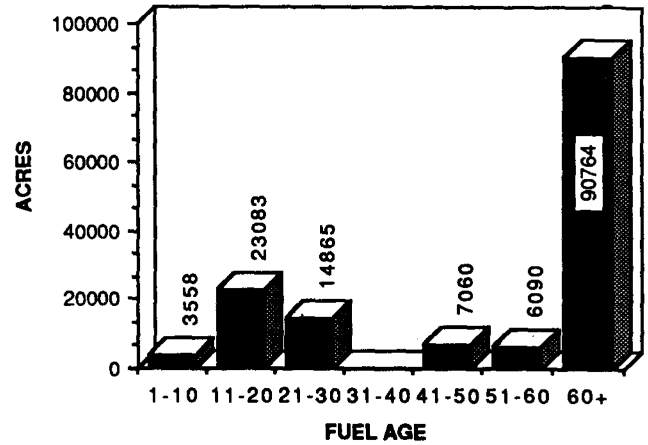

Figure 2--Distribution of fuel age classes consumed during the 1970 Laguna fire.

General Weather Conditions

Twelve of the 23 instances of reburning occurred under Santa Ana weather conditions. Another 6 to 8 occurred under "southwest flow" conditions. The "southwest flow" is a very general weather classification in which surface winds blow onshore from the west or southwest, and is the most common summer weather influence in southern California. It includes the subtropical high aloft condition (Schroeder and others 1964) during which many of the largest fires in the state have occurred. Unfortunately, upper air maps, which were generally not available, are necessary to differentiate the subtropical high aloft condition from other southwest flow types. The Santa Ana condition, in which surface high pressure exists over the Great Basin area, generates some of the most extreme burning conditions in the world. High winds and low humidities are endemic to this weather type. Fires occurring under these two major weather types, combined, have accounted for nearly 50 percent of the acreage consumed by large fires in San Diego County since 1910 (Dunn 1987).

Six of the 11 largest fires in San Diego County between 1940 and 1985 burned at least 1000 acres (400 ha) of young chaparral fuels. These fires, of course, generally occurred under the severest burning conditions. However, reburns also occurred in relatively small fires. It is difficult, therefore, to evaluate the flammability of young fuels based on the data available. It remains clear, nonetheless, that young chaparral fuels will burn readily under the conditions that generate large wildfires. A good example is the Pine Hills fire of 1967 (fig. 3), which originated in forest and chaparral fuels 40 or more years old. Pushed by a "moderately intense" Santa Ana condition, the Pine Hills fire blackened nearly 3200 acres (1280 ha) of chaparral

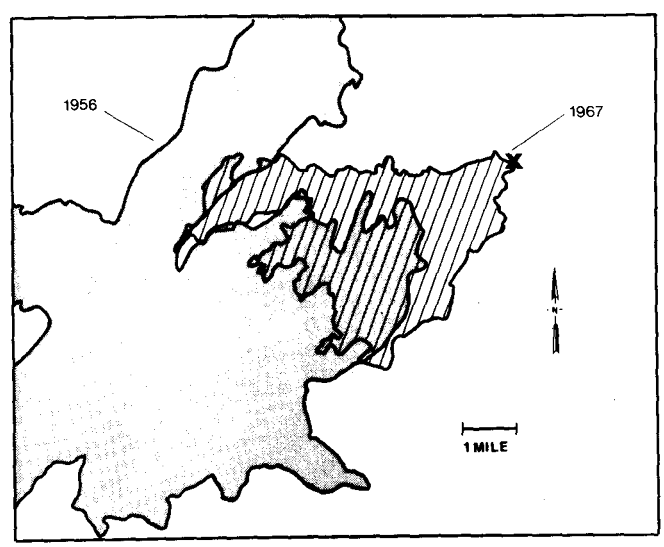

Figure 3--Perimeters of the 1956 Inaja and 1967 Pine Hills fires.

and oak woodland that had last burned in the 1956 Inaja fire. When the Santa Ana winds died down on the second day of the fire, southwesterly upslope winds developed, pushing the fire front back into the burned area and halting its advance into the 11-year-old fuels. (Schroeder and Taylor 1968).

Location of Origin of Fires in Reburns

Of the 23 recorded instances where large areas of young fuels reburned, 19 originated in older fuels and then spread into young fuels. Only in two instances did fires clearly originate in young fuels. In the other two instances, it was unclear in which age class the fire began. Though it is impossible to make a statistical statement based on 23 burns, it appears that most reburns occur in fires that originate in older age classes. In the two fires which began in young fuels, one (the 1985 Miller fire) began in grass fuels and carried into the chaparral during a severe subtropical high aloft condition which spawned a dozen other large fires in the state. Severe weather conditions were also present during the 1981 Oat fire in Los Angeles County, which also began in grassland fuels (Radtke 1982). The Oat fire was driven by strong Santa Ana winds into 11-year-old chaparral fuels and consumed over 17,000 acres (6,800 ha) in less than 11 hours. All told, 99.6 percent of the area burned in the Oat fire supported fuels 11 years old or less.

Effect of Young Fuels on Large Fires

Though prescribed burning may provide increased opportunities for fire suppression by decreasing fire intensities (Harrell and others 1987), there is some question as _to whether young fuels, whether they burn or not, actually do much to inhibit the spread of large fires. The interaction of the 1985 Wheeler fire in Ventura County with 2-year-old fuels left by the 1983 Matilija fire is a case in point. The Wheeler fire consumed nearly 108,000 acres (43,200 ha) during a severe subtropical high aloft condition and was the largest fire in California that year (Dunn and Piirto 1987). Eighty-five percent of the area burned by the fire supported chaparral fuels.

The Matilija fire began as a prescribed burn in mixed chaparral fuels, projected to cover about 500 acres (200 ha). However, the fire escaped to cover 4600 acres (1840 ha) before it was finally contained. The Wheeler fire first encountered the Matilija burn at about the time it began its period of most rapid spread, pushed by temperatures exceeding 100° and humidities around 25 percent. Though approximately 75 percent of the 2-year-old fuels resisted reburning, they posed little barrier to the spread of the Wheeler fire, which split into two fronts and went entirely around the Matilija burn (fig. 4). In 11 hours, the Wheeler fire nearly doubled in size and continued burning for 12 more days before it was declared controlled.

The question must therefore be asked whether burning parcels of 500 or even 5000 acres (200-2000 ha) has much effect on reducing the hazard of truly large fires. Though prescribed burning may inhibit the spread of fires under moderate conditions, the practice may do little to affect the large fires that occur under severe conditions; those fires, like the Wheeler fire, that consume the majority of the acreage burned and do the most damage.

CONCLUSIONS

Large fires occurring under severe conditions are clearly capable of burning through or entirely around areas of young chaparral fuels. The fact that these fuels do indeed burn and do not necessarily inhibit the spread of large fires may have a significant impact on fuel management planning and prescribed burning policy. A closer look needs to be taken at the actual benefits provided by prescribed burning for fire hazard reduction and the conditions under which these benefits occur. Prescribed burning provides benefits for wildlife habitat and watershed management and, used in conjunction with other suppression features such as fuelbreaks, rods and fuel type boundaries, may yield benefits in fire suppression. However, whatever benefits prescribed burning may provide, alone it will not stop intense wildfires. Prescribed burning policy must be formed with this reality in mind.

ACKNOWLEDGMENTS

This study was supported in part by a grant from The Conservation Agency.

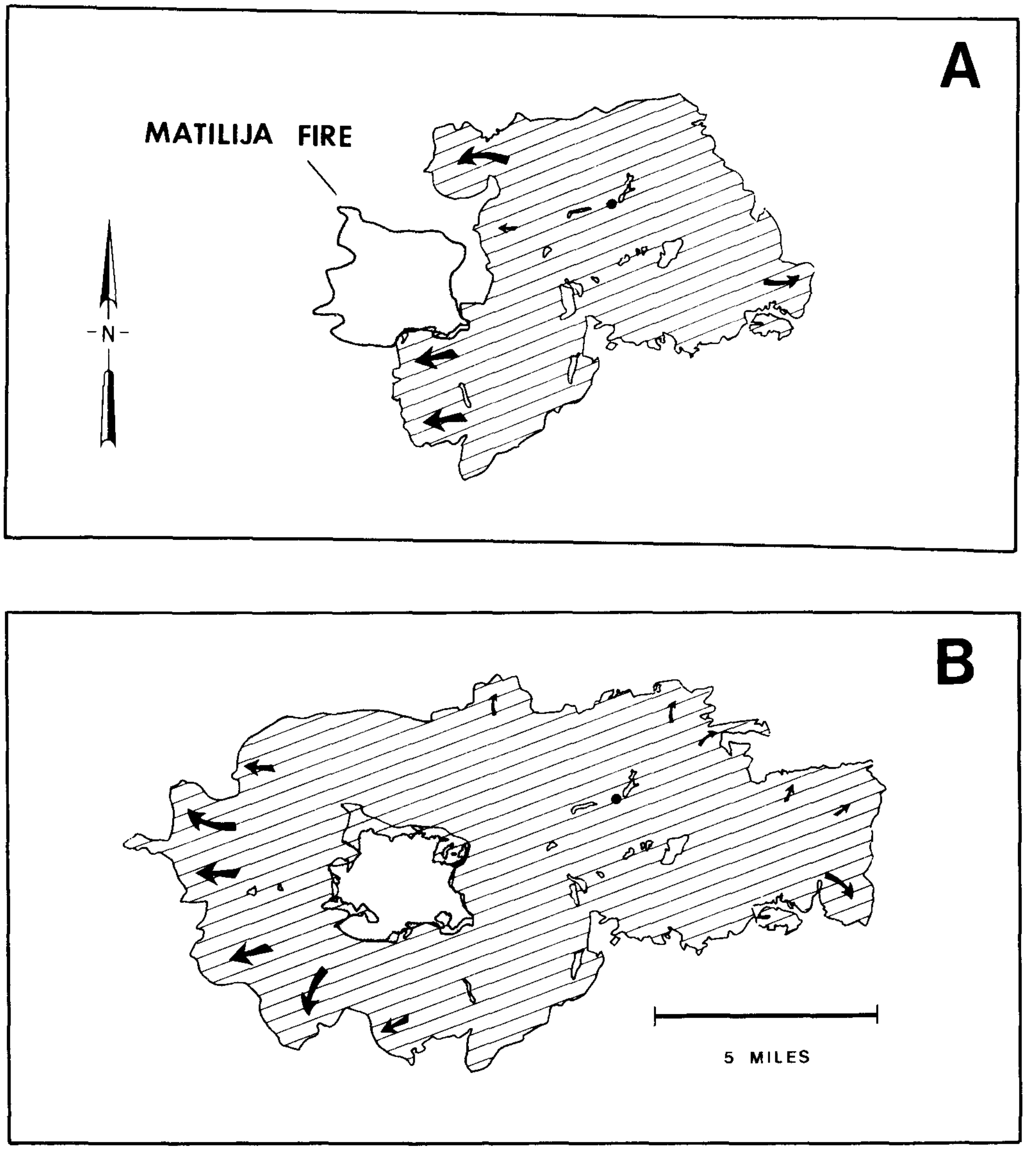

Figure 4--Two stages of the Wheeler fire: A, 1000 hours, July 3, 1985. Current size: 30,410 acres (12,164 ha); B, 2100 hours, July 3, 1985. Current size: 59,490 acres (23,796 ha). Arrows indicate areas of active fire spread. Adapted from Dunn and Piirto (1987).

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Cost-Effective Fire Management for Southern California's Chaparral Wilderness: An Analytical Procedure[1]

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Abstract: Fire management has always meant fire suppression to the managers of the chaparral covered southern California National Forests. Today, Forest Service fire management programs must be cost effective, while wilderness fire management objectives are aimed at recreating natural fire regimes. A cost-effectiveness analysis has been developed to compare fire management options for meeting these objectives in California's chaparral wilderness. This paper describes the analytical procedure using examples from a study currently being conducted for the Los Padres National Forest, and discusses some preliminary results.

The southern California National Forests (Los Padres, Angeles, San Bernardino, and Cleveland) were originally established to protect the area's chaparral watersheds from fire, but now bear many additional demands and values. For example, over 35 percent of the Los Padres National Forest is designated or proposed wilderness. The goal of fire management in Forest Service wilderness is the restoration and continuance of natural fire regimes (USDA Forest Service 1986). Fire is a natural component of chaparral ecosystems. But, restoring fire's natural role will be difficult and expensive given past fire suppression policies and present urban-wildland interface conditions. Forest managers are now charged with restoring this natural fire regime in a cost-effective manner.

Prescribed lightning fire management, prescribed burning, and the use of "appropriate suppression responses" are legal wilderness fire management options (USDA Forest Service 1984). Prescribed lightning fire management is the use of highly detailed prescriptions to monitor and manage lightning fires. The prescriptions include environmental conditions, air quality constraints, fire and weather histories, limitations on size and intensity, probability that the fire will remain within acceptable size limits, safety of firefighters and the public, and availability of suppression forces if the fire leaves prescription and must be suppressed. Prescribed burning is similar to prescribed lightning fire management except that Forest Service land managers ignite the fires on their own time schedule when burning conditions are optimal (which often means out of the natural fire season).

Any fire not classified as a prescribed fire is a wildfire and must receive an appropriate suppression response. But, Forest Service policy no longer requires this response to be intensive suppression efforts aimed at keeping the fire as small as possible (a control response), as a wildfire can now be contained or confined. Containment is to surround a fire with minimal control lines and utilize natural barriers to stop its spread. Confinement is to limit a fire's spread to a predetermined area principally by the use of natural barriers, preconstructed barriers, and environmental conditions (USDA Forest Service 1984).

Southern California Forest managers are planning to continue intensive suppression efforts on wildfires and to maintain chaparral wilderness fire regimes through prescribed burns (USDA Forest Service 1988). However, appropriate suppression responses or lightning fire management might be more cost-effective approaches (that is, might reduce the costs and impacts of fire suppression and allow more acres to burn under natural conditions). This paper has three main objectives:

1. To describe a cost-effectiveness analysis (CFA) to compare fire management options for California's chaparral wilderness.
2. To illustrate its use through examples from a study being undertaken for the San Rafael and Dick Smith Wilderness Areas on the Los Padres National Forest.
3. To discuss some of the preliminary findings of the Los Padres Analysis.[3]

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[3]The Los Padres CEA is currently being conducted through a McIntire Stennis grant from the Natural Resources Management Department at Cal Poly, San Luis Obispo, and in cooperation with the Los Padres National Forest. The final results of this CEA will be available by April, 1989 from the authors.

BACKGROUND

Several economic models have been developed to evaluate fire management programs (Saveland 1986; Mills and Bratten 1982; USDA Forest Service 1987). Most of these models are intended for large-scale fire management planning and cannot evaluate the effects of anything less than intensive suppression responses. Furthermore, many are based on the "cost plus net value change" (C + NVC) economic efficiency criterion.

For example, the National Fire Management Analysis System (NFMAS--USDA Forest Service 1987) is used for fire management planning by all National Forests. NFMAS develops fire occurrence probabilities from forestwide fire occurrence histories, then uses computer models of fire behavior and suppression efforts to determine average annual suppression costs and burned areas for different fire management budget levels and management emphases (for example, allocating more dollars for fuels management than for suppression forces or prevention programs). From burned area estimates, net resource value changes caused by fire (NVCs) are calculated based on acreage burned by intensity level. The budget level and management emphasis which minimizes the sum of fire management costs and NVCs is considered the most efficient.

This type of analysis is inappropriate for wilderness fire management planning for several reasons. First, basing fire occurrence rates on large area fire histories misrepresents the fire regime of small, remote wilderness areas. The greatest cause of fire on the Los Padres is arson, while almost 80 percent of the fires in the Dick Smith and San Rafael Wilderness Areas during the past 25 years were remote lightning-caused fires, often occurring under less than extreme fire weather conditions (Los Padres fire reports from 1963-87).

Second, expected cost and burned area values are derived from fire containment computer programs. Two different programs are available, but neither is capable of evaluating the effects of any suppression response other than control.

Third, current limitations of Cost + Net Value Change (C + NVC) evaluations make it inadequate for wilderness fire management planning. C + NVC is a cost-benefit economic efficiency analysis. Cost-benefit analysis is a comparison of the costs of meeting an objective against the returns or benefits. In theory, economic efficiency is achieved when the costs equal the benefits, or by the minimization of the sum of the costs and benifits (as in C + NVC). To be complete, a cost-benefit analysis must include a measure of all of the costs and all of the benefits (Williams 1973). To define the change in a resource's value caused by fire, the value of the resource itself must be defined. Currently, C + NVC evaluations include values for most primary forest resources such as timber, minerals, and forage. Net Value Changes (NVCs) have also been placed on many wilderness outputs such as water, fish and wildlife habitat, and recreational use. But, these resources are only secondary outputs, or by-products of wilderness (Saveland 1986). Without a measure of the primary value of the resource--wilderness itself in this case--a cost-benefit analysis will be incomplete, and very likely misleading (that is, the effects of fire on these by-products is not the same as its effects on a wilderness ecosystem).

Despite these problems, most of the work that has been done on the economics of wilderness fire is based on C + NVC (Condon 1985, Mills 1985). One exception is an economic evaluation of fire management options for a portion of the Frank Church--River of No Return Wilderness Area (Saveland 1986). This analysis is a cost-effectiveness comparison of four different fire management programs. The costs of each alternative are the expected annual suppression costs. And, "effectiveness" is the approximation of the average "natural" annual burned area based on what fire history studies reveal:

> Plant communities require a certain amount of fire, just as they require a certain amount of precipitation .... Altering the average annual burned area would be like altering the average annual rainfall (Saveland 1986).

Though Saveland's analysis was for a different fire regime, his definitions and much of his methodology are appropriate for California's chaparral.

COST-EFFECTIVENESS ANALYSIS

A cost-effectiveness analysis (CEA), in its truest form, is a comparison of the costs of different alternatives, where each alternative will meet the desired objectives, or have the same effects. There are five key elements of a CEA: the objectives; the alternatives; the costs; the model; and a criterion for ranking the alternatives (Quade 1967).

The Objective

The main objective of wilderness fire management is to allow lightning fire to play, as nearly as possible, its natural ecological role in restoring the natural fire regime. Research suggests that the natural fire return interval for chaparral is about 30 years (Minnich 1983, Byrne 1979). The fire records of the Los Padres (1911-1987) suggest that the chaparral burns every 45 years (USDA Forest Service 1988). The 45-year rotation was chosen for this study. Using the 45-year return interval, an average of over 5,000 acres (2024 ha) of the 231,500 acre (93,687 ha) study area would have to burn annually.

The Alternatives

Four alternatives were chosen for the Los Padres CEA. Alternative 1 is the Forest Service's past policy: Control all wildfires regardless of cause, and attempt to meet annual burned area objectives through prescribed burning. Alternative 2 is the fire management strategy proposed in the Los Padres' Land Management Plan: Contain all fires which occur under low intensity and control all moderate to high intensity fires, while pursuing an active prescribed burning program (USDA Forest Service 1988). Alternative 3: confine all low intensity starts, contain moderate to high intensity starts, and control only the starts which occur under extreme fire weather conditions. Alternative 4: the same as 3 with the addition of an approved plan for prescribed lightning fire management. Alternatives 3 and 4 would be augmented by a smaller prescribed burning program to meet average annual burned area objectives, since more acres will have been burned by wildfires and lightning caused prescribed fires.

The Costs

All measurable variable costs must be included in a CEA. Fixed costs, such as those for staffing lookouts or firefighting units, do not have to be included in the analysis as long as they remain the same for each alternative. For example, the appropriate suppression force staffing levels for the Los Padres were determined through NFMAS and by budget constraints. These levels are based on an average of over 100 fires per year, while less than 2 fires a year occur in the case study area. Therefore, wilderness fire suppression strategies will not affect forestwide personnel requirements. The variable costs that must be considered are annual suppression costs, NVCs, and costs of any prescribed burns.

The Model

The model is a simplified representation of the real world which includes all of the relevant features. The role of the model is to predict the costs of each alternative and the extent to which each would meet management objectives (Quade 1967). Decision trees can be used to evaluate alternative fire management programs in the face of uncertainties about future fire occurrences, weather, behavior, and sizes (Hirsch et al. 1981). Decision trees develop expected values, which are probability weighted averages of all possible outcomes. Probabilities are derived from fire history records for fire management planning. Cost and burned area figures can be drawn from historic fire management records, records of adjacent or comparable fire management programs, or some form of fire gaming if no historic or comparable records are available. Every wildfire is a unique event and past fire occurrences cannot be considered predictors of future fires. Thus, "expected values" are not predictions (actual future values may or may not be similar), but they do provide relative values for comparison. Therefore, decision trees make an appropriate model for our CEA.

A Criterion

The criterion for ranking alternatives is dependent upon the agency's goals and objectives. In wilderness fire management planning, many different rankings are possible. Prescribed lightning fire management might be justified even if it was more costly than intensive suppression. For example, the National Park Service considers acres burned under natural conditions more important than the cost of a fire management program (Agee 1985). Both cost and burned area are important considerations for Forest Service wilderness fire management programs, so both values must be developed.

THE LOS PADRES EXAMPLE

The decision tree for Alternative 1 of the Los Padres study (table 1) illustrates the values and probabilities which must be developed for a wilderness fire management CEA. A decision tree must be completed for each alternative, using the same probabilities, but with different suppression responses, and thus different cost and burned area values. The probabilities for each branch of the trees were calculated from the last 25 year fire history of the San Rafael and Dick Smith Wilderness Areas (including the proposed 16,500 acre--6,680 ha--addition to the San Rafael Wilderness Area).

For the first branch of the trees, all 44 fires (34 lightning- and 10 person-caused fires) were mapped by point of origin. Representative fire locations (R.L.s) were chosen to represent each historic fire (fig. 1). The probability of a fire occurring at each R.L. was based on the number of fires represented by that R.L. For example, 13 fires are represented by R.L. 1, thus 13/44, or 0.296 is the probability of a fire occurring under conditions represented by R.L. 1. The second branch was the probability of occurrence by cause. These probabilities were dependent upon the fires represented by that R.L. For example, 5 lightning- and 8 person-caused fires were represented by location 1, thus the probability of an R.L. 1 fire being caused by lightning is 5/13, or .385.

For the third branch, the 1400-hr weather observations from nearby weather stations were retrieved for the day of ignition of each historic fire and the following 30 days to develop month-long weather patterns. Weather patterns were divided into groups, based on the Santa Barbara Ranger District's prescribed burn weather parameters:

	Low	Optimum	High
Fuel stick			
1 hour	8	6	5
10 hour	14	9	7
100 hour	18	13	9
Live fuel moisture	110	70	60
Relative humidity (pct)	50	30	25
Wind speed (mi/hr)	0	5	13
Temperature (degrees F)	60	75	85

These parameters represent a window of environmental conditions which would allow for safe management of a prescribed fire, but still meet burned area objectives. Environmental conditions must remain within these parameters throughout the life of a fire for it to still be "in prescription." Prescriptions must be modified for site specific conditions and burn objectives, but these general parameters were used to distinguish fires burning under "good" conditions (low to moderate fire intensity level) and fires burning under "bad" conditions (high to extreme intensity). Four weather patterns were distinguished: (A) weather that started within prescription parameters and continued within these parameters for at least two weeks (a good-good pattern); (B) weather that started within prescription, but soon moved out of prescription (a good-bad pattern); (C) weather that started out of prescription, but soon cooled to within prescribed conditions (a bad-good pattern); and (D) weather that started out of prescription and stayed out (a bad-bad pattern). These patterns were then used to calculate the probability of lightning- and person-caused fires occurring under each pattern (table 1). For example, 15 of the 34 lightning fires occurred under "good-good" weather patterns so the probability is 0.441.

Once probabilities have been calculated, cost and burned area values must be developed for probability weighting. These values should represent the range of potential fire costs and sizes. Saveland (1986) used average costs and sizes drawn from similar fire management programs on adjacent wilderness lands. To date, no contain or confine suppression responses, lightning fire management, or prescribed burns have been

Table 1--The decision tree for Alternative 1 of the Los Padres CEA, representing the control of all fires.

	REPRESENTATIVE LOCATION	CAUSE	WEATHER PATTERN[1]	SUPPRESSION RESPONSE[2]	GAMED SIZE (acres)	EXPECTED ANNUAL BURNED AREA (acres)	GAMED COST (dollars)	EXPECTED ANNUAL COST (dollars)
ALTERNATIVE 1 (1.76 fires)	R.L. 1 (.296)	Lightning (.385)	A(.441)	CR	0.5	0.0	6,351	562
			B(.118)	CR	10.0	0.2	7,230	171
			C(.147)	CR	118.0	3.5	74,942	2,210
			D(.294)	CR	40.0	2.4	32,238	1,901
		Person (.625)	A(.100)	CR	0.5	0.0	6,351	207
			B(.200)	CR	10.0	0.7	7,230	471
			C(.200)	CR	118.0	7.7	74,942	4,880
			D(.500)	CR	40.0	6.5	32,238	5,348
	R.L. 2 (.341)	Lightning (.933)	A(.441)					
			B(.118)					
			C(.147)					
			D(.294)					
		Person (.067)	A(.100)					
			B(.200)					
			C(.200)					
			D(.500)					
	R.L. 3 (.364)	Lightning (.938)	A(.441)					
			B(.118)					
			C(.147)					
			D(.294)					
		Person (.062)	A(.100)					
			B(.200)					
			C(.200)					
			D(.500)					
			(preliminary) TOTALS:			(21ac/yr)		($15,650/yr)

[1]Weather patterns are divided into four groups based on prescribed burn parameters: A = good-good weather pattern; B = good-bad weather pattern; C = bad-good weather pattern; D = bad-bad weather pattern.

[2]Suppression response options include: control (CR); contain (CA); confine (CF); or prescribed lightning fire management (Px).

attempted in southern California wilderness. Thus, a fire gaming approach was taken.

Fire gaming is the prediction of representative fire sizes by fire management professionals. Predictions are based on the interactions of estimated fire behavior conditions and given suppression force responses (Harrod and Smith 1983). It is an acceptable technique to predict final fire sizes and costs, and has been used for Forest Service fire management planning in the past (Joseph and Gardner 1981). Gaming accuracy is dependent upon the abilities and knowledge of the fire garners (Harrod and Smith 1983). The Los Padres fire management personnel participated in fire games for the 1980 National Forest budgeting process. A 1982 fire started near a gamed location and under similar weather conditions. The resulting 825-acre (335-ha) fire was very similar in both costs and size to the gamed fire. The same gaming team (as many of the members as possible) was reassembled to game representative fires for our study.

Fire gamers include the Forest's Fire Management Officer (F.M.O.), the Assistant F.M.O., the Fuels Management Officer, the recently retired Fire Prevention Officer ("Budget 80" games leader), and two District F.M.O.s (one recently retired). All but the Forest F.M.O. were involved in the 1980 games so little training was necessary.

Gaming materials include 15-minute topographic maps and aerial photographs of the R.L.s and adjacent areas, Mylar (clear plastic) overlays, representative weather patterns (one pattern from each of the four categories was chosen for each R.L.), a list of the resources that would be dispatched initially to each R.L. (based on the Forest's current dispatch plan), a fire history map which includes all fires 300 acres (121 ha) or greater that occurred in the study area since records were started, and assorted tabulation sheets to record resources used, hours, miles of travel, and other suppression costs that would be encountered during the life of each "gamed fire" (Harrod and Smith 1983).

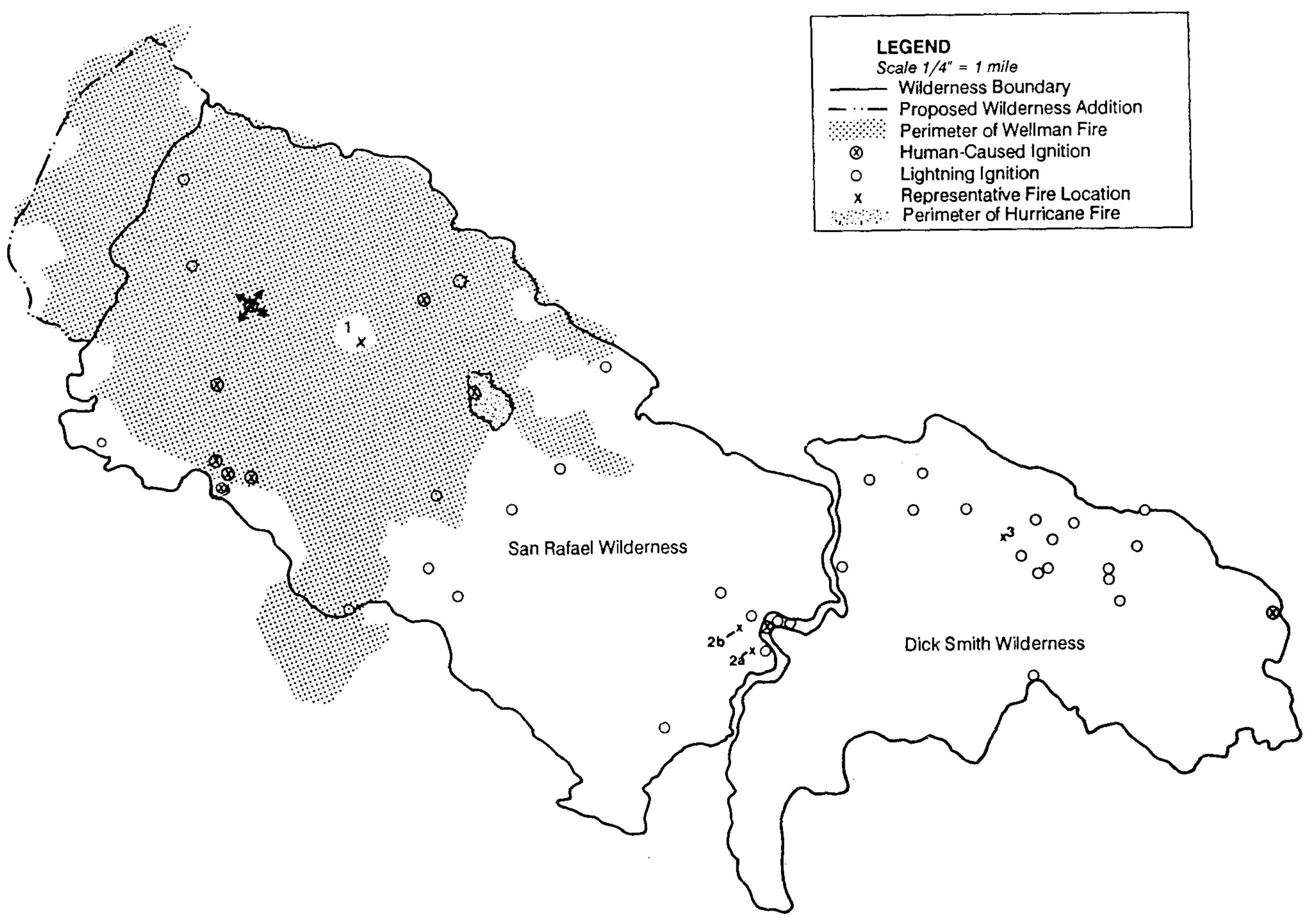

Figure 1--The last 25 year fire history of the Dick Smith and San Rafael Wilderness Areas and the corresponding representative fire locations.

Actual games consisted of first mapping an overlay of the free-burning fire spread (without any suppression efforts) from time of ignition to report and then for a series of time periods thereafter. Fire spread rates were determined from the computer program "Firecast" (Cohen 1983) based on slope and fuel conditions at the R. L., and the given weather pattern. Spread rates were subjectively modified by garners to account for changes in fuel conditions, local weather patterns, diurnal weather changes, and changes in topography as fires spread. Four weather patterns were gamed at each location. Fires started under "good" weather conditions were then gamed four times: controlled, contained, confined, and managed as a prescribed fire. Fires starting under "bad" conditions were only controlled and contained since these fires would be out of prescription, and good weather would be necessary to confine fires in these unbroken fuelbeds.

PRELIMINARY RESULTS

The results of the fire gaming for R.L. 1 and some preliminary gaming results for R.L. 2 are presented in table 2. The R.L. 1 values were then run through the appropriate decision tree for their use and preliminary expected values for average annual cost and burned area were calculated (table 3). For example, all fires were controlled in Alternative 1, thus the control gaming results were used throughout this tree (table 1). Alternative 2 results represent the containment of both fires which started under good weather conditions and the control of the two which started under bad conditions. Alternative 3 results represent the confinement of the first two fires and the containment of the latter two. Alternative 4 results were calculated similar to the third, except that 25 percent of the low intensity lightning caused fires (both good conditions) were considered prescribed fires.

Table 3 also compares each alternative's cost per area managed and average annual cost per burned area for fires represented by R.L. 1. The figures for cost per area managed are based on 68,500 acres (27,722 ha), or 29.6 percent of total wilderness.

NVCs are determined by the size and intensity level of each gamed fire. The Los Padres currently calculates these values for all 300+ acre (121 ha) fires. Only three gamed fires burned more than 300 acres at R.L. 1 and these were in a "low valued" watershed. Thus, the NVC's for R.L. 1 do not have much effect on our preliminary expected annual costs. NVCs will be

Table 3--Average annual cost, cost per area managed, average annual burned area, and average annual cost per area burned for four alternative fire management programs for Representative Fire Location 1 of the Dick Smith and San Rafael Wilderness Areas[1]

	Average annual cost	Cost per acre (ha) managed	Average annual burned acre (ha)	Average annual cost per burned acre (ha)
Historical (before suppression)			1500+ (607+)	
Alternative 1	$15,650	$0.23 ($0.57)	21.0 (8.5)	$745 ($1841)
Alternative 2	$15,096	$0.22 ($0.55)	21.0 (8.5)	$719 ($1776)
Alternative 3	$13,898	$0.20 ($0.50)	153.1 (62.0)	$91 ($224)
Alternative 4	$13,908	$0.20 ($0.50)	153.1 (62.0)	$91 ($224)

[1]Representative Fire Location 1 represents 29.6 percent of the case study fires, thus figures are calculated from 29.6 percent of the 231,500 acre (93,687 ha) site, or 68,500 acres (27,722 ha).

Table 2--Final size and cost figures for gamed fires.

	CONTROL		CONTAIN		CONFINE		Px Lightning Fire	
	Size (acres)	Cost ($)	Size (acres)	Cost ($)	Size (acres)	Cost ($)	Size (acres)	Cost ($)
Representative fire location 1								
Good-good weather pattern	0.5	6,351	0.5	3,883	4.0	2,919	4.0	3,207
Good-bad weather pattern	10.0	7,230	10.0	4,365	457.0	6,135	457.0	6,622
Bad-good weather pattern	118.0	74,942	270.0	45,791	N/G		N/G	
Bad-bad weather pattern	40.0	32,238	390.0	39,086	N/G		N/G	
Representative fire location 2[1]								
Good-good weather pattern	0.5	2,903	0.5	2,548	99.0	3,038	738.0	28,697
Good-bad weather pattern	66.7	36,759	780.0	41,367	[2]2300+	100,000+		

[1]Cost figures for representative fire location 2 have not been formally reviewed by the fire garners, thus they are subject to minor changes. However, the relationships between responses will probably not change.

[2]The confine fire game for good-bad weather at R.L. 2 has not yet been completed, but the fire will be over 2,300 acres and will probably cost over $100,000. The prescribed fire game has not been started.

important cost considerations when more valuable watersheds become involved.

DISCUSSION

The values presented in table 3 are only preliminary results as they represent only one R.L. And, R.L. 2 results cannot be run through the decision trees until all of the games for that R.L. have been completed. The values in table 3 are provided to illustrate calculation techniques and some of the results that can be developed through this type of CEA. Expected annual suppression costs and burned areas will be much higher when the decision trees are completed, and the relationships between the alternatives will probably change. Therefore, comparisons of these preliminary values are difficult to justify since they are based on such a small database (one series of games).

Despite this small database, some patterns have become evident. Many fire management personnel consider the use of confinement or prescribed lightning fire management impossible in decadent chaparral fuelbeds (for example, two fire garners before our games began). Both responses were successful at R.L. 1 (the least expensive response under good-good weather and only slightly more expensive than containment under good-bad). This R.L. is covered by fairly young (22-year-old) mixed chaparral. The relatively light fuels and extraordinarily high humidities in both good weather patterns helped confine the fires. This pattern is not being repeated at R.L. 2, where confinement and prescribed lightning fires are becoming the most expensive responses. These results suggest that confinement or prescribed lightning fire management will not be cost effective, at least until much more of these decadent fuelbeds are broken up by younger fuel mosaics and our ability to reliably forecast weather conditions increases.

Containment was feasible under moderate conditions at R.L. 1 (little more than half of the cost of control under good-good weather, and the least expensive response under good-bad), and this pattern is continuing at R.L. 2 (though it was slightly more expensive than control under the moderate intensity, good-bad fire at R.L. 2). Containment was also the least expensive response under the highest intensity fire gamed thus far (bad-good weather at R.L.1), which suggests that containment could provide some substantial fire suppression savings on fires in these wildernesses. This pattern will be closely monitored in future games, as more data will be necessary for validation of this finding.

Expected annual burned areas illustrated the anticipated pattern of more area burned under the less intensive suppression responses. The annual expected burned area for alternatives 3 and 4 is somewhat low. But, this can be attributed to the young fuels and high humidities which led to moderate burning conditions. Gamed fire sizes for confinement and prescribed lightning fires are becoming much higher at R.L. 2, and the higher pattern is probably more representative of these wildernesses.

Some unanticipated, but valuable observations of these early fire games are not directly related to our CEA. The garners--all "old-school" firefighters--originally raised questions about the feasibility of containing or confining chaparral fires. Our games compelled these fire managers to consider what they would do when required to use these responses in the field, either through policy or when suppression forces are not available.

Another important finding of our preliminary games is the value of the Forest's pre-attack manuals. During the 1960's and early 1970's, the Los Padres was divided into "pre-attack blocks". Each block was mapped, marked, and signs were posted designating potential dozer lines, hand lines, helispots, water sources, fire camp locations, and other valuable fire suppression information. These plans have recently been discarded by many fire management staffs, but have proved invaluable to the garners for the confinement and containment responses. This suggests that if appropriate suppression responses are ever to be utilized on the Los Padres, these manuals should be updated and made more readily available to fire management personnel. Even if control remained the most appropriate suppression response for the Forest, up-dated pre-attack manuals would be valuable tools for prescribed burn managers.

SUMMARY

In summary, cost-effectiveness analysis is appropriate for wilderness fire management planning. Decision trees help us predict future fire occurrence potentials, and intensive gaming efforts can help us predict fire sizes and costs associated with the implementation of appropriate suppression responses and prescribed lightning fire management. These values are important to land managers who are now faced with the cost-effective management of natural fire regimes in chaparral wilderness. This type of analysis is especially valuable for southern California land managers who have little field experience with any fire management program other than intensive suppression efforts and off-season prescribed burning, especially given the risks associated with fire in volatile chaparral ecosystems. Fire games are not only providing a valuable evaluation of appropriate suppression responses and prescribed lightning fire management, but are also proving educational to "old school" fire management personnel and illustrating some potentially cost effective alternatives to intensive suppression efforts.

ACKNOWLEDGMENTS

We thank the following persons, all with the Forest Service, U.S. Department of Agriculture: Santa Lucia and Santa Barbara Ranger District Fire Management Officers Chet Cash, and Tom Goldenbee (recently retired), Los Padres National Forest Fire Prevention Officer Dennis Ensign (recently retired), Forest Fuels Management Officer Harold Cahill, and Forest Assistant Fire Management Officer Lonnie Briggs for their extensive time commitments to fire gaming; Economist Eric Smith of the Regional Office, San Francisco, CA. for technical counsel; Economist Armando Gonzalez-Caban of the Forest Fire Laboratory, Riverside, CA. for technical counsel and review; Santa Barbara Ranger District Fuels Management Officer Jim Shackelford for technical review; and Jane Cochrane of the Los Padres' Business Management Staff for extensive editorial review. This project was funded by a McIntire Stennis grant from the Natural Resources Management Department, California Polytechnic State University, San Luis Obispo.

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Demography: A Tool for Understanding the Wildland-Urban Interface Fire Problems[1]

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Abstract: Fire managers across the nation are confronting the rapidly developing problem created by movement of people into wildland areas, increasing what has been termed the wildland-urban interface. The problem is very complex from the standpoint of fire planning and management. To plan and manage more effectively, fire managers should identify three types of interface areas, each with its own unique set of demographic factors, local land use, and fire protection problems. By examining and understanding how future trends will affect fire protection tactics and strategy in each of the interfaces, managers should be able to plan ahead--to be proactive rather than reactive in relations with the public and its leaders. To do this, however, fire managers should understand how population dynamics--demographics--influences the area that they manage.

The American people, it seems, are as mobile and restless as the desert sands. One has only to read an article on population dynamics (demographics) to appreciate how rapidly the nation's population changes. If we are to do a good job managing the forested land in what has been generally termed the "wildland-urban interface" we need to know something about these changes and how they may affect our future plans.

Almost all of us concerned with wildland management are becoming familiar with the wildland urban interface area concept. We may have seen the growing problem throughout the nation where there has been a dramatic increase during the past 10 to 15 years in the number of people moving into the wildlands (Davis 1986). While the trend toward rural living has reflected the public's appreciation of rural land values, it has also greatly increased the number of primary residences, second homes, and retirement homes located in proximity to the nation's forests, woodlands, and watersheds (Davis and Marker 1987; Hughes 1987a). In some areas of the nation, mobile homes seemingly spring up overnight. Vast areas of the United States now contain high-value properties intermingled with native vegetation.

Although the fire problem is often spectacular, these developing areas have other management problems that we are just beginning to appreciate. These include limited timber harvesting options, recreation pressure, and such serious threats as pollution and erosion (Rice 1987; Walt 1986). Changing patterns of population distribution have important implications for the way we manage our forests today and the way we must plan to manage them in the future. However, to understand the implications of these patterns, we first need to define the wildland-urban interface. The term can mean different things to different people.

TYPES OF INTERFACE

Almost every part of the nation has a wildland-urban interface fire problem. Interface areas can range from deserts where a flush of flammable growth follows a rain to undeveloped park land inside a major metropolitan area. Three types, each with its own demographic characteristic and land management problems have been defined (NW/UFPC 1987).

- Mixed Interface or Intermix
- Classic Interface
- Occluded Interface

Not only are the variety and density of vegetation and size and spacing of homes and other structures variable and complex in these different interfaces, but the location and movement of people are different from one to the other, and their population trends change rapidly over time and frequently in different directions (Rogue 1985).

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The intermix

The intermix ranges from single homes or other buildings scattered throughout the wildland area to medium-sized subdivisions. Typical are summer homes, recreation homes, ranches, and farms in a wildland setting. Usually these are isolated structures surrounded by large areas of vegetation-covered land, but, this is not always true. Wintergreen, a development in the Blue Ridge Mountains of Virginia, contains 600 homes and 1,000 condominium units, yet the nearest large town or city is 40 miles away (Graff 1988). When a fire starts, the individual homes are very hard to protect because few fire agencies can provide a fire truck or two for each house that may be threatened in a major fire.

The classic interface

By far the greatest number of people live in (and are currently moving into) what can be called the classic interface. This is the area of "urban sprawl" where homes, especially new subdivisions, press against the wildland (Hughes 1987b). Fires starting in adjacent wildland areas can propagate a massive flame front during a wildfire, and numerous homes are put at risk by a single fire which sometimes overwhelms fire protection forces and water supplies. Typical examples include California's San Gabriel Mountains, Colorado's Eastern Front, and New Jersey's Pine Barrens.

The occluded interface

An occluded interface is characterized by isolated areas of wildland within an urban area. The same demographic trends that influence the classic interface affect this one. As cities grow together to make a super city, islands of undeveloped land are left behind (Engels 1985). Sometimes, these are specifically set aside as natural parks. Again, they may be steep, difficult places that are unsuitable as building sites. Frequently they present a fire threat to adjacent homeowners.

The type of intermix is not always clearcut. Small towns and villages may contain both classic and intermix areas depending upon how the "downtown" tends to mix with wildland vegetation at the city's fringes.

Variability in Fire Protection Responsibility

The fire problem is much complicated by a patchwork of legal and organizational requirements and constraints for fire protection (Irwin 1987). For example, some States have specific legal requirements for the protection of structures in the wildland. Others have no legal responsibility and neither train their personnel nor purchase the specialized equipment needed for structure protection. Many agencies with thousands of acres of wildland within their jurisdictions may be unprepared to fight a wildland fire effectively.

Most Californians are aware of the southern California fire problem. Examples are the Bel Air Fire in 1961 in which 484 homes were destroyed; and the 1980 "Panorama Fire" in which 286 homes were burned and four people killed. However, the worst interface disaster confronted by modern fire protection agencies occurred during the Maine fires of 1947. In a series of late fall fires, 16 persons lost their lives and 2,500 were made homeless: nine communities were leveled or practically wiped out, and four other communities suffered extensive damage. One witness describes the roads as "crowded with people, livestock, cars, teams, and wheelbarrows fleeing before the fire." At one town--Bar Harbor--fleeing residents had to be rescued by Coast Guard, Navy, and private boats in a Dunkerque-like operation (Wilkins 1948).

The problem is truly national in scope--Florida's Palm Coast Fire in which 99 homes were lost (Abt and others 1987) and a 1987 fire near Spokane in which 24 homes were lost are recent examples. The worst year in this decade from a structure fire standpoint was 1985. By the end of the year, over 83,000 wildfires had burned almost 3 million acres, destroyed or damaged 1,400 structures and dwellings, caused the deaths of 44 civilians and firefighters, and cost the Federal, State, local fire agencies, and private industry over 400 million dollars in firefighting costs (NW/UPFC 1987).

With the more or less steady increase in population, we can only expect the loss to increase unless specific concrete steps are taken to change the situation. The nationwide concern for this problem cannot be over-emphasized. In addition to many States, the USDA Forest Service considers it a "major issue" and has joined in a partnership with U.S. Fire Administration and National Fire Protection Association in sponsoring the national "Wildfire Strikes Home" initiative.

DEMOGRAPHY

Demography is the discipline that seeks a statistical description of human population and its distribution with respect to (1) structure (the number of the population; its composition by sex, age, and marital status; statistics of families, and so on) at a given date, and (2) events (births, deaths, marriages and termination of marriage) that take place within the population over a given period (Pressat 1972).

The demography of the wildland-urban interface

Who are the new interface residents? The people moving into the interface are a varied group. In one locality the newcomers were found to include five categories (Herbers 1986; Sweeney 1979):

- Commuters, more and more of whom are willing to travel long distances from a mountain setting to jobs in urban areas.
- The retired, who want to trade in urban problems such as crime and smog for a remote and more peaceful home in the mountains or foothills.
- Younger dropouts from the urban rat race. Many of these with families want to raise their children in a simpler, less pressured lifestyle, away from the problems of city schools and rush-hour traffic jams.
- Older, more successful corporate executives who wish to exchange long hours spent in often well-paying jobs for even longer hours spent launching their own small businesses.
- The poor, who may find that it is the only place they can afford to live. Often a home (or mobile home) in the wildland is far less expensive than similar accommodations in more developed places.

Part of the reason for this growth is that the postwar "baby boom" generation has reached the age of achieving a relatively high level of education and affluence. Growing up during the "ecological revolution" of the 1960's and early 1970's, many in this group are attracted to the interface as a good place to own a home and raise a family (Herbers 1986). Forest Service planners seeking acceptance of their forest plan know that this group has characterized itself as being concerned with environmental issues.

Other major reasons include improved transportation and communication. Superhighways and interstate routes have enabled people to live in outlying areas and commute to a job in the city (Bradshaw 1987; Engels and Forstall 1985; Long and others 1983). Some people believe they can escape crime and pollution problems by moving to a more rural setting. However, as suburban areas age--particularly the classic and occluded interfaces--they may take on the characteristics of the inner city, with its poverty and ethnic problems (Newitt 1983). It is very important for a wildland manager to identify the demographic mix of people and tailor management strategies accordingly. The manager must also be aware of projections and trends in order to deal effectively with these diverse publics.

Trends

For most of our history, this nation's cities have grown at the expense of rural areas. However, from the mid-1940's to the late 1970's there was a widespread reversal of this trend. Hastened by the baby boom, there was a population shift from urban to nonmetropolitan (suburban and rural) living. The result has been a major increase in the number of people who have moved into or adjacent to our nation's forests and woodland areas (Kloppenburg 1983; Scapiro 1980). In these areas, urban development interfaces (or intermixes) with wild or undeveloped land. Most people have moved into this area for the amenity values or for economic reasons unrelated to traditional rural land uses, such as forestry or farming.

California Example

As a close-at-home example of these trends, California has long appealed to American movers (Sanders 1987). By the late 1960's, however, the number of States from which California gained migrants had fallen, and it began to lose migrants to Oregon, Washington, and Nevada, as well as to Oklahoma and Virginia. Between 1975 and 1980, California had net losses in migration exchanges with all 10 of its western migration partners. But this net loss of 420,000 people to these 10 other States was offset by a net gain of 534,000 people from the rest of the country, chiefly from the Northeast and Midwest.

Not long ago Oregon residents sported bumper stickers asking Californians to visit but not to stay. Now such fears have been allayed because Oregon is once again exporting people to California. Between 1984 and 1985, California gained migrants from Oregon and Washington, reflecting the decline in the logging industry and rising unemployment in the Northwest.

So far in the 1980's, only 2 of California's 10 migration partners in the West continue to be net importers of Californians. Between 1984 and 1985, these 10 States sent a net of 19,000 people to California. This is a mere trickle, however, compared to the 420,000 migrants that California lost to these States between 1975 and 1980.

Demographic projections aside, local populations respond to the ebb and flow of local economics. Falling lumber prices and farm losses can wipe out a decade of demographic momentum, while a new business can rekindle a stagnant population. Keeping up with these changes is vital to local planners, school administrators--as well as the forest or fire manager (Sternlieb and others 1982).

DEMOGRAPHY AS A PLANNING TOOL

How can demography help us predict these change so that we can plan ahead for them? While projections of the need for governmental services, including fire protection, road construction, and water development may be well developed in the classic and occluded interfaces because of the proximity of metropolitan areas; however, this is rarely true for the intermix. Fire managers should have this information so that they can plan and budget for their organizations. They should know how population projections and land development plans relate to critical fuels and steep terrain so they can work "before the fact" with community planners and land developers. They should know something about the ethnic and cultural background of anticipated new residents so they can better tailor prevention efforts.

Data useful for demographic analysis exists only rarely in official statistics in the specific form that it is needed. The peculiar character of the specific problems raised frequently requires the collection of appropriate information through special inquiries or surveys. This is particularly true of the small towns comprising the intermix.

Sources of Information

For the United States, there are two primary sources of demographic data. The first of these is the comprehensive reports of the census population, which tabulates data assembled each 10 years since 1790. The latest of these enumerations was made in 1980, and most of the published results have been made available (Kennedy and others 1987).

The population census provides a portrait at a given instant of a population that is constantly changing under the influence of the events--births, deaths, and migrations--that occur in it. Thus the census measures the size of the population by sex, age, marital status, education and so on at the date of the census. The various kinds of information that have been collected can be combined in many ways, and they can concern an entire country, or some given part of the country (region, State, county, or city). Little by little, the field of investigation has been extended to include groupings much smaller and more specific than the usual national or regional aggregates. These broader studies cover not only small administrative or other units (cities, villages, natural regions), but also human categories that are not territorially well defined (for example wildland-urban residents). The Census Bureau is now gearing up for the 1990 survey--its largest ever.

The second fundamental source are the annual. publications issued by the National Center for Health Statistics, which tabulates data on births and deaths. Departments of public health in most of the States also publish vital statistical data for their respective States, some of them slightly earlier and in somewhat greater detail than those given in the reports issued by the National Center for Health Statistics. For more general demographic material, the Statistical Abstract of the United States, issued annually by the Government Printing Office, is a convenient and reliable source of information.

How demographic information will be used

The most dramatic innovation of the 1990 census is the automated mapping system known as TIGER (Topologically Integrated Geographic Encoding and Referencing), which will enable the Census Bureau, working with the U.S. Geological Survey, to develop computerized maps covering the entire United States (Keane 1988). The TIGER process uses geographical information system (GIS) technology, that translates the intersection of boundaries of one type of information--census related information for example--with information from another geographic feature. It will be possible to overlay population density maps with vegetation type, slope class, and aspect to produce fire risk and hazard maps. The next step will be development of population projection models that will predict risk and hazard 5 or more years into the future. Next will be the use of one of several existing fire spread models to overlay the population projection, with areas that will have a statistical probability of burning in future fires. Thus, a fire manager will be able to display to local policy and planning officials detailed information on the areas likely to be threatened by future wildfires and the homes and population that will be at risk unless mitigation measures are taken.

Land managers will be able to use GIS developed maps, containing demographic information, to predict where a growing population will impact on their fire protection strategies and timber, recreation, and other land management plans.

Demographic training and skills

Demographers are trained to conduct surveys, estimate small-area populations, and prepare demographic reports. Most are employed to make market surveys and projections for retail business--the location of a new shopping center for example (Stephen 1988). Demographers should have a strong background in statistics and computer modeling, and the ability to "crunch" large amounts of data. They should be well aware of the great wealth of existing information. Many are familiar with geographic information systems, a field that the Forest Service is rapidly applying. Computer skills should include both computer programming, including writing new programs for specific analysis, and expertise in using statistical packages such as SPSS and SAS.

By examining and understanding how future population trends will affect fire protection tactics and strategy in each of the interfaces, managers should be able to plan ahead-to be proactive rather than reactive in relations with the public and its leaders in managing the wildland-urban interface and its forestry and fire problems.

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Controlled Burns on the Urban Fringe, Mount Tamalpais, Marin County, California[1]

Thomas E. Spittler[2]

Abstract: The California Department of Conservation, Division of Mines and Geology provided technical assistance to the California Department of Forestry and Fire Protection in assessing potential geologic hazards that could be affected by proposed prescribed burns on Mt. Tamalpais. This research yielded the following conclusions: (1) landsliding and surface erosion have contributed to the denudation of Mount Tamalpais; (2) Debris flows and surface erosion could affect property and the environment on and below the mountain; (3) The removal of chaparral will reduce the stability of the slopes; and (4) Prescribed burning may reduce the risk and lessen the destructive effects of wildfire and may therefore have significantly less impact on both landsliding and surface erosion than the probable wildfire event modeled by the California Department of Forestry and Fire Protection.

The last conclusion is based on the following considerations: controlled burns separated in time and space would expose smaller slope areas to the effects of rainfall than would a wildfire; a hot wildfire would damage the soil much more than a cool controlled fire; slope-damaging fire-fighting measures, such as tractor-constructed fire trails, would not be needed for controlled burns; and areas of geologic concern, such as colluvial-filled hollows, will be included in the development of the prescription for controlled burns on Mount Tamalpais.

Mount Tamalpais, the highest point in Marin County, lies just 20 km. north of San Francisco (fig. 1). The slopes of the mountain rise steeply free the encroaching urbanization of Mill Valley, Larkspur and Kentfield. These slopes support a dense stand of decadent chaparral that poses a significant fire hazard to the surrounding area (Perry 1984).

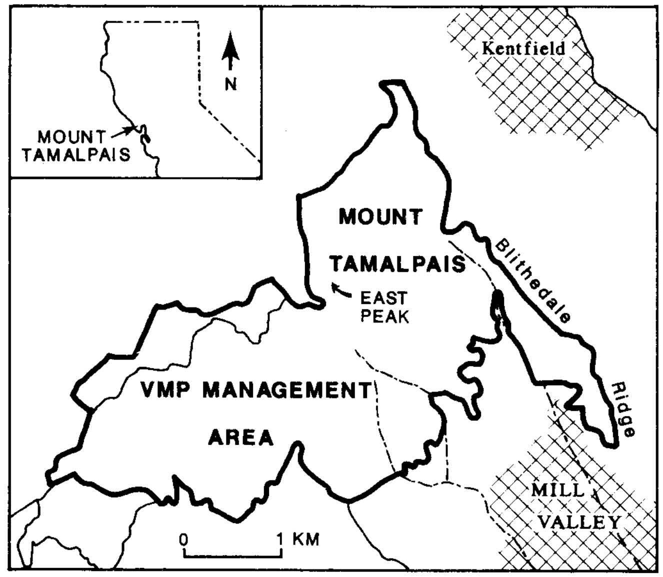

Fig. 1 Location map showing the boundaries of the Mount Tamalpais Vegetation Management Plan area and its relation to urbanizing areas of Marin County.

The Marin County Fire Department, in cooperation with the California Department of Forestry and Fire Protection, has developed a plan to reduce the threat of catastrophic wildfires through the use of prescribed burns on the south-facing slopes of Mount Tamalpais on lands managed by the Marin Municipal Water District and the Marin County Open Space District. These agencies do not, however, wish to reduce the wildfire hazard by increasing the hazards of erosion, flooding, and debris flow activity to unacceptable levels. Therefore, technical assistance was requested from the California Department of Conservation, Division of Mines and Geology to assess geologic hazards, particularly erosion and slope stability, that could be affected by proposed Vegetation Management Program controlled burns.

The primary goal of the prescribed burns is to create a mosaic of age and size classes of chaparral vegetation on the south face of Mount Tamalpais to limit the wildfire hazard (Selfridge 1966a). Four multiple burn areas, totaling 300 ha in size, are designed to break up brush fields that threaten life and property in the town of Mill Valley (Selfridge 1986a).

[1]Presented at the Symposium on Fire and Watershed Management, October 26-28, 1988, Sacramento, California.

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Within these multiple burn areas, 20 to 35 percent of the vegetation, approximately 80 ha, are anticipated to be burned in the next year the project is active. This represents 8 percent of the 1000 ha area managed by the Marin Municipal Utilities District and the Marin County Open Space District.

The initial burns will be in the winter or early spring, when live fuel moistures are high, to allow for better fire control (Selfridge 1986b). Once the extreme fire hazard is reduced, controlled burning will take place during favorable weather conditions in the fall (Selfridge 1986b). Fall burns are desirable because they mimic natural conditions and would pose less of a threat to endangered plant and animal species. The ultimate goal of the vegetation management project on Mount Tamalpais is to burn approximately 5 percent of the chaparral vegetation each year to maintain a 20 year rotation of the fire climax species (Nehoda 1988). In this context, the review by the Division of Mines and Geology addresses the entire management area.

GEOLOGIC SETTING

Bedrock

Mount Tamalpais is underlain by the Marin Headlands terrane of the Franciscan Complex (Blake and others 1984). Bedrock exposed in the proposed burn area is a weakly metamorphosed lithic sandstone with serpentinite along fracture zones (Wright 1982). The sandstone beneath East Peak is very hard and strong and is cemented by authigenic tourmaline. This tourmalinized sandstone is recognizable within sane transported old landslide masses (Rice 1986). The serpentinite is highly sheared, very weak, and has failed as earth flows, slumps, and debris slides on relatively gentle slopes.

Colluvium

Colluvium accumulations in bedrock hollows are a main source of debris flow landslides (Reneau and Dietrich 1987). On Mount Tamalpais, the dominant colluvium is poorly consolidated with sandstone clasts supported by a poorly sorted sandy matrix. This is the type of material that is highly prone to failure by debris flow events (Ellen and Fleeting 1987).

Most of the areas of colluvium accumulation on Mount Tamalpais can be identified by their surface morphologies, however, some of the colluvium-filled, pre-existing topographic lows are not reflected in the surface topography (Wright 1982). These obscure hollows were identified by using false color infrared aerial photographs taken during the summer. Because of the greater moisture capacities of colluvium compared with the surrounding soil, plants growing over the hollows are not stressed by water deficiencies to the same degree as those over bedrock. This difference in plant stress causes the strong differences in the reflectances of near infrared radiation (Glass and Slemmons 1979) that was used to identify the obscure, colluvium-filled bedrock hollows. All of the identified colluvium deposits larger than approximately 1 ha, both those that are exhibited in the surface topography and those that are not, are shown on fig. 2.

A few small areas were observed where the colluvium consists almost entirely of serpentine detritus. For geotechnical purposes, the serpentine colluvium was included with either the serpentinite or the serpentine-derived landslide deposits over which it lies.

Landslides

Rotational landslides, earthflows, debris slides, and debris flows (nomenclature from Varnes 1978) were identified in the Mount Tamalpais Vegetation Management Plan burn area (fig. 2). Features with physiomorphic properties that are associated with rotational sliding, but which have been modified by erosion, are the most extensive in the area. These large, apparently deep-seated features are interpreted to be related to an earlier, very wet climate.

Earthflows have affected the serpentinite and serpentine colluvium in the western portion of the Vegetation Management Plan area. Portions of the individual earthflows are prone to reactivation in response to accumulated soil moisture, whether the area is burned or not.

Debris slides of unconsolidated rock, colluvium, and soil that have moved downslope along relatively shallow failure planes were identified as affecting both the Franciscan Complex sandstone and the serpentinite. Most of the mapped debris slides are along roads and trails where cut banks are continuing to ravel. In a few locations, sidecast fill and portions of the underlying soil and colluvium have failed. Debris slides were also identified in steep areas well away from cut or fill slopes. Unlike the large, deep ancient rotational landslides that may be thousands or even tens of thousands of years old, the surface morphology of a debris slide rapidly degrades by erosion. The debris slides mapped on fig. 2 are either active or recently active.

The most abundant type of landslide mapped in the Mount Tamalpais Vegetation Management Plan burn area is the debris flow. Debris

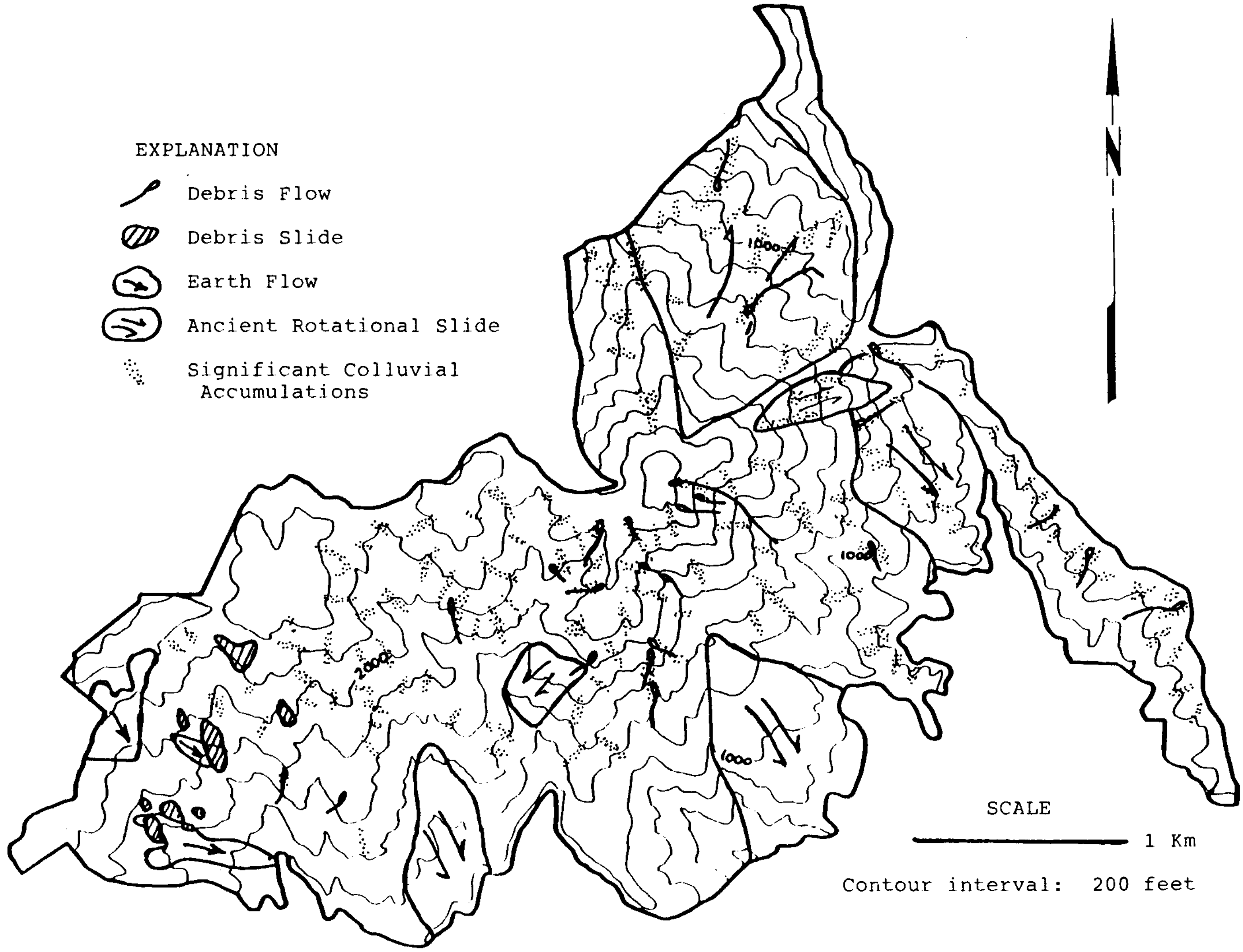

Fig. 2 Map of landslides and colluvium deposits within the Mount Tamalpais Vegetation Management Plan

flows, often termed debris avalanches when velocities are greater than about 10 miles per hour (Varnes 1978), are shallow landslides that fail as muddy slurries during periods of intense precipitation (Campbell 1975). Many researchers -- for example, Dietrich and Dunne (1978) and Lehre (1981) -- have recognized that most debris flows start in swales or hollows at heads of small hillside drainage courses. These are areas where the potential source material (loose colluvium) and ground water accumulate, resulting in focused high pore-water pressures in weak materials (Reneau and others 1984).

Three debris flows on the east face of East Peak originated on hiking trails where surface water was intercepted and diverted into the swales. The debris flows that are mapped on fig. 2 are almost all products of a major storm which occurred free January 3 through January 5, 1982.

Lehre (1981) measured erosion and sediment discharge in a small watershed on the western slope of Mount Tamalpais and concluded that debris slides and flows account for most of the sediment yield there. Sediment that is mobilized during years without extreme flow events generally returns to storage, chiefly on the lower parts of slopes and in channel and gully beds and banks. Large net removal of sediment occurs during storm events with recurrence intervals greater than 10 to 15 years (Lehre 1981). Most of the stream channels on Mount Tamalpais have transported sediment without resulting in severe aggradation.

THE EFFECTS OF FIRE ON SLOPE STABILITY AND EROSION

The primary effect of a fire is the removal of vegetation. Where slopes are steep and soils are cohesionless, as on Mount Tamalpais, stems and trunks of vegetation and organic litter support loose clasts, preventing them from rolling downslope. Burning removes the mechanical support, allowing material to dry ravel. Wells (1981) quotes USDA Forest Service research that dry ravel is responsible for aver half of all sediment movement on many slopes.

A major effect of fire on chaparral soils is the production of a water-repellent layer beneath the soil surface. DeBano (1981) noted that chaparral plant communities produce a degree of water repellency under normal conditions because organic substances are leached from the plant litter and coat sand and coarse-grained soils (the surface area-to-volume ratio of fine-grained soils limits the effectiveness of the production of water repellency). The water-repellent material under unburned chaparral stands is only partially effective in restricting infiltration. When wildfire sweeps through a chaparral stand, the soil temperatures may reach 840°C (DeBano 1981). This volatilizes the organic water-repellent materials which follow temperature gradients downward into the soil. The vaporized substances then condense on mineral soil particles and produce an extremely water-repellent layer. The 1- to 5-centimeter-thick layer of soil that overlies the water-repellent zone is highly permeable and erodible.

Following a high-intensity fire, the effective water storage capacity of the soil mantle is estimated to be reduced by 20 times or more (Wells 1981) and rainfall quickly exceeds the soil's storage capacity. The excess water that cannot penetrate through the hydrophobic layer saturates the surficial wettable layer, which may fail as small-scale debris flows (Wells 1987). This material, in addition to the surface rill and gully wash, rapidly runs off into stream channels.

Peak flows in stream channels downslope of burn areas may occur with less of a delay from rainfall peaks than those in unburned watersheds. Flood peaks are often much higher and more capable of eroding stored sediment. The high flows of sediment-charged water can erode large quantities of material and transport it as debris torrents (debris flows that are initiated in stream channels as opposed to colluvium-filled hollows).

Landsliding, principally debris flows, has also been shown to increase in frequency after vegetation is removed from met-stable slopes (Rice and Foggin 1971). The maximum incidence of landsliding occurs several years after a fire because of the time it takes for the soil-reinforcing root biomass to decay and for the water-repellent layer to be disrupted and permit infiltration.

One additional negative environmental effect of wildfire that has received little attention is the damage to the soil caused by fire suppression efforts. During a major wildfire, earth moving equipment is used to build fire trails. These trails are often several tractor blades wide and may trend directly down steep slopes. It is fairly common for fires to jump individual lines, often requiring the excavation of many parallel downslope firebreaks. Each of these disrupted areas is often significantly more prone to erosion than the burned hillslopes adjacent to them. Additionally, erosion control structures, such as waterbars, are often placed where they divert water onto unstable slopes.

Sediment derived from burned areas is routed through drainages. If a channel is capable of carrying the additional load, the excess sediment is transported to an area of long-term deposition. If, on the other hand, the material eroded from burned slopes exceeds the carrying capacity of the stream, the sediment will settle out, aggrade the channel, and cause additional erosion and sedimentation.

EFFECTS OF FIRE SUPPRESSION

Fire suppression has been successful on Mount Tamalpais since the Great Mount Tamalpais Fire of 1929 burned 117 houses in Mill Valley. Fuel management has not been practiced during this time, resulting in the current critical fire hazard conditions. When the age class of chaparral vegetation is over 20 years, as is the case in the Vegetation Management Plan area on Mount Tamalpais, the live-to-dead plant ratio -- and therefore the potential for burning - increases (Perry 1984). The accumulation of fuel in areas where fire suppression has been practiced also results in fires that are unprecedented in size, intensity, and environmental damage when compared to unmanaged areas (Dodge 1972). Minnich (1983) compared adjacent portions of southern California, where fire suppression has occurred, with northern Baja California, where there has been little or no wildfire control. Although approximately 8 percent of the chaparral acreage was burned by wildfires in both areas during his study, in Baja California the fires occurred as many small events that were distributed in time throughout each summer, while in southern California, a few large, often catastrophic fires burned in the late summer and fall.

The stream channels on Mount Tamalpais evolved during the time when small wildfires produced a mosaic of age classes of chaparral vegetation. The carrying capacity of some of these channels would likely be overwhelmed if a large storm event were to occur following a catastrophic wildfire. Flood damage during the winters after the wildfire occurred could likely extend below the limits of the burn.

PRESCRIBED BURNING EFFECTS

Prescribed burns have the same types of impacts as wildfires on erosion and slope stability, but the intensity and areal extent of these impacts is much less. Prescribed burns can be small and separated in time and space. This results in a far lower exposure of soil to precipitation during any one time interval. Prescribed burns can be designed to prevent side slopes from being denuded from ridgetop to canyon bottom. Dry ravel may occur, but only a portion of the dry ravel on the side slopes will travel any significant distance downslope. Water- repellent conditions do not develop to the same degree under prescribed burn conditions, and changes in the particle size distribution reported by Wells (1981) are less pronounced. This is particularly true if burns are conducted when soils are wet. The law-intensity burns may induce hydrophobic soils, but only a thin layer of erodible material is likely to lie above a discontinuous water-repellent zone. Also, the use of heavy grading equipment on slopes, such as occurs when fighting wildfires, is much less likely to occur if an area is burned under prescribed conditions.

A controlled burn of only a portion of a watershed will have less of a potential for producing damaging peak flood events or surface erosion than would a complete removal of vegetation by a wildfire. As described above, prescribed burns do not produce the continuous water-repellent layer found beneath wildfire areas. Therefore, much of the post-fire rainfall infiltrates into the soil and does not rapidly run off. Smaller quantities of sediment are likely to erode more frequently from areas managed through controlled burns as compared to less frequent post-wildfire floods which may trigger catastrophic erosional events.

CONCLUSIONS

Fire is a natural part of a chaparral landscape. Where fires have been suppressed for a long period of time, such as on Mount Tamalpais, the effects of the ultimate wildfire event may be large. Removal of the vegetation, fire damage to the soil, and ground disturbance by fire suppression equipment will all contribute to a situation where post-fire floods and debris flows could pose a severe risk to lives and property downslope of the wildfire area. These conditions may also decrease slope stability in many areas. The proposed controlled burning program should lessen the potential for off-site damage due to floods, debris flows, and landslides from Mount Tamalpais.

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Synthesis and Summary: Land Use Decisions and Fire Risk[1]

Theodore E. Adams, Jr.[2]

Rapidly chancing land use patterns are having a significant impact on watershed management and the included elements of fuel management and fire protection. The complexity of watershed management was defined in the Watershed Management Council's publication prepared for the first conference. This publication, California's Watersheds, emphasized that all land use activity has an impact, that individual impacts can be cumulative and even synergistic. In California, the impact of development on fire effects and fire protection is a grand example.

In my summary, I will not follow the schedule of individual papers presented. I will, instead, structure the review and my comments to emphasize the impact of demographics and copulation growth on fuel management and fire protection, concerns stated or implied in all presentations.

Jim Davis described the application of demography, the study of population characteristics, to the analysis and prediction of fire management problems. In so doing, he suggested that demography and the social sciences might be more important than new technology to land managers and fire protection agencies.

In Cooperative Extension, we assessed the character of populations in several Mother Lode counties to help us design better information delivery systems. These counties were among 10 that represent less than 10 percent of the state's land mass and, in 1980, represented less than 3 percent of the population. However, in 75 percent of this 10-county area, the population growth rate is at least three times that of the state as a whole. The area represents watershed resources that present major management and fire protection problems.

[1]Presented at the Symposium on Fire and Watershed Management, October 26-28, 1988, Sacramento, California.

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A preliminary analysis of the population, based on questionnaires, indicated that the average age of respondents is 54 years. Two-thirds have some college and nearly one-third have a Bachelor's or higher degree. Slightly less than half grew up in a city or a town. Half of the remainder had a rural childhood, but they did not grow up on a farm or ranch. Slightly less than two-thirds have owned their property for less than nine years. As a group, this audience appears to be middleaged, well educated, with a predominantly urban or nonfarm background, and they have owned their rural property for a relatively short time. These characteristics are not peculiar to California. A similar evaluation appears in Wildfire Strikes Home, the report of the National Wildland/Urban Fire Protection Conference published in 1987.

Added to the problem of changing land use patterns is the variability in fire protection responsibility. Agencies responsible for structural protection often are not trained to handle wildfire situations; agencies such as the California Department of Forestry and Fire Protection (CDF) and U.S. Forest Service often find themselves ill prepared to address structural fire protection in wildlands situations. This problem was discussed in the report Wildfire Strikes Home, which describes the disastrous fire season of 1985 and documents the costs in lives and property that resulted from lack of preparedness in communities across the country where the interface (or intermix) exists. During 1985, 44 people died from fire-related causes, 1,400 structures and homes were destroyed or damaged, and nearly $.5 billion was spent in fire suppression. The bill for all costs and damages amounted to more than $1 billion. Given the projected growth in rural areas, losses can only increase unless a concerted effort is made to address the problem. Locally, the Forty-Niner Fire near Grass Valley in Yuba County and the Miller Fire near Vacaville in Solano County, fires that occurred in California this summer, are examples of what can be expected. The Forty-Niner Fire destroyed more than 100 homes and structures.

As Jim points out, growth is occurring for a variety of reasons related to the perceived quality of life and a desire by urbanites to escape urban problems. However, as rural communities grow, urban-related problems emerge, often aggravated by the physical setting, and frequently become watershed and fire management problems.

Currently, technology represents a major part of fire management programs, and use of prescribed fire is a consideration in development of new policy. Both Bob Martin and Tom Spittler discussed the value of this important tool for protection. They described the technical use of fire and the use of fire for fuel management driven by socioeconomic concerns and changing demographics.

The extent of the use of prescribed fire deserves attention. On State Responsibility Areas in California, CDF is burning less than 50,000 acres (123,000 hectares) annually using this tool under the Chaparral Management Program (CMP). This is considerably less than the targeted 120-150,000 acres (296-370,000 hectares) discussed in the Program EIR. In many areas, the acreage burned may prove inadequate from a fire protection standpoint.

Tony Dunn pointed out the inadequacies of current prescribed fire programs created as a deterrent to large wildfires in San Diego County. Current prescribed fires burn too little acreage to create an effective age class mosaic. Under severe fire weather conditions, wildfires burn through small acreages of young fuels. He emphasizes that young fuels may provide increased opportunities for fire suppression by decreasing fire intensities, but the scale created must be greater. Tony's analysis might be applied to the entire state.

He concludes by saying that prescribed fire, as currently used, can be effective only when considered as an adjunct to other measures such as fuel breaks, roads, and changes in fuel type. However, the value of fire as a tool to enhance wildlife habitat and promote watershed management gives it an intrinsic value that can be exploited when fire protection is a consideration.

Fire as a management tool cannot be used without caution. Limits on its employment are imposed by several constraints, not the least of which is urbanization of wildlands. But other, less obvious limits exist, and one of these is social tolerance for fire and the smoke it produces. Air pollution is a major environmental concern, and smoke from agricultural burning, industrial sources, and home fireplaces is being regulated.

Jim Agee addressed the issue of smoke pollution in his presentation. He suggested that the social environment in which fire ecosystems exist has had a more significant impact on fire policy than the physical-biological environment. Continued evolution of fire as a management tool probably will be controlled by air pollution concerns, the impact of smoke from prescribed fire on air quality. The prediction is that air pollution will be perceived as a greater threat than wildfire. This will occur for two reasons: (1) air quality is more easily dealt with because of existing organizational structure, and (2) smoke from prescribed fire will probably affect more people more often than smoke from wildfire. Social acceptance of prescribed fire may depend on recurring disasters.

Jim also pointed out that funding for control and use of fire occurs differently and contributes to the problem; fuel treatment is billed to operating (budgeted) funds, and losses foregone from wildfire are not counted as benefits. (However, in California, the CDF acknowledges the fire protection value of prescribed fire in computing costs and benefits of a CMP burn.)

Public perceptions of wildfire and its impacts also complicate the use of fire as a management tool. People wrongly assume that wildfire will not occur twice in the same place, and that the occurrence of a wildfire reduces future vulnerability.

Jim concluded by emphasizing that social factors and the level of public understanding drive development of fire policy. This must be recognized by land managers and fire protection personnel in the development of future policy.

Future fire management policies must be flexible to respond to both changing demographics and social pressure. Alternatives to current and projected strategies must be developed to insure effective response to growing fire risk. This might be done by examining selected scenarios as is being done for wildfire management in Southern California chaparral wilderness.

As reported by Chris Childers, evaluation of the cost-effectiveness of fuel management and fire suppression strategies for chaparral wilderness is being accomplished through fire gaming. To date, the most valuable Dart of this exercise has been the experience gained by fire fighters who have had to consider their responses to different management strategies.

Gaming is essentially reactive and assumes a set of rules. However, at the interface and under the pressure of changing land use patterns, fire management agencies cannot easily define those rules. For gaming to be effective, rules for development must be established. Lack of such rules has forced the adoption of limited strategies.

The CDF, with responsibility for protection of one-third of the state, has been forced by rural development to set as its Primary objective the protection of homes and structures. As described by Rich Schell and Dianne Mays, this objective is complicated and hazardous to achieve because state laws and local ordinances do not effectively address the need for defensible space. Unlike other disasters, wildfire does not receive the attention from planners that is given to other accepted forms of disaster.

CDF funding is based on wildland fire protection needs, not population growth and development. Program deficiencies must be addressed by application of fire protection standards through local planning and design.

In Dianne's presentation, she emphasized that CDF must be involved in local planning to help mitigate the impacts of growth and development. Fire protection expertise is needed to ensure adoption of measures providing adequate defensible space. The key is planning for and building in a basic level of protection around structures that would include adoption of minimum standards for specific elements of a fire protection program. This and related needs were emphasized by Hal Malt in his luncheon presentation.

Legislation establishing minimum fire-safe standards for greenbelts, water supplies, and building materials was passed by the California Legislature this year. Legislation like this, SB-1075, often is necessary, but it is reactive to the problem. Planning for fire protection is at its best when it is proactive and recognizes trends.

This year the California Legislature passed, but the Governor failed to sign, legislation that would have required updating of county general plans. Counties would have been required to develop and implement policies in the Safety, Land Use, and Conservation Elements for mitigation of the wildfire threat. CDF would have been authorized to provide its expertise in the process.

At this time, there is, perhaps, too great an emphasis on technology (building materials, greenbelts, prescribed burning) as the primary solution to fire risk. This observation is based on public perceptions and politics that are forcing adoption of strategies that may not allow aspects of technology to adequately support reduction of the threat from wildfire.

Human behavior is part of the problem. People are not enthusiastic about strategies that include zoning and density requirements. This has been shown through surveys. The surveys also revealed that people are generally unwilling to bear direct costs for hazard mitigation. These responses suggest that people may expect disaster relief that the future cannot guarantee.

While developing rules to define fire gaming plans, it will be necessary to direct effort towards modification of human behavior. As Jim Agee pointed out, the social environment is an important consideration. This means an educational program to raise public awareness and develop support for needed change.

I believe it is fair to assume that those of us in management, service, and educational programs must, in the future, focus less on technical solutions to physical-biological problems in the field of watershed management and more on the problems generated by socioeconomic concerns. It appears that demography must become one of our studies and that sociology along with psychology will be useful tools, as well, These "new" tools will help us find out how far apart are the bars of our cage and how best to modify this confinement.

Effects of Fire on Watersheds

Effects of Fire on Chaparral Soils in Arizona and California and Postfire Management Implications[1]

Leonard F. DeBano[2]

Abstract: Wildfires and prescribed burns are common throughout Arizona and California chaparral. Predicting fire effects requires understanding fire behavior, estimating soil heating, and predicting changes in soil properties. Substantial quantities of some nutrients, particularly nitrogen and phosphorus, are lost directly during combustion. Highly available nutrients released during a fire are deposited on the soil surface where they are immobilized or lost by erosion. Information on the effect of fire on physical, chemical, and biological soil properties provides a basis for discussing short- and long-term consequences of postfire rehabilitation treatments on total. nutrient losses, changes in nutrient availability, decreased infiltration rates, and erosion. Arizona and California chaparral show both similarities and differences.

Chaparral occurs mainly in Arizona and California. It covers 1.3 to 1.5 million ha as a discontinuous band across Arizona in a northwest to southeast direction (Hibbert and others 1974). California chaparral, and associated woodlands, cover about 5 million ha extending from Mexico north to the Oregon border (Wieslander and Gleason 1954; Tyrrel 1982).

Prescribed burns and wildfires occur frequently throughout chaparral in Arizona and California. In California, wildfires can occur during any month of the year, although they are most severe during Santa Ana winds in late summer and fall. Most severe fire conditions in Arizona are in spring and early summer before summer rains start and then again during late fall after the summer monsoon season has ended. Prescribed burning can be done in both types throughout the year, although most burns are conducted during periods of less severe burning conditions. Because both wild and prescribed fires occur frequently throughout chaparral, land managers are continually asked to assess fire effects on different resources while developing postfire rehabilitation plans. The objectives of this paper are to (1) compare Arizona and California chaparral, (2) outline an approach for assessing fire effects in chaparral soils, (3) present a detailed summary of fire effects on soil properties in chaparral, and (4) discuss postfire management concerns.

ARIZONA AND CALIFORNIA CHAPARRAL

Both California and Arizona chaparral originated from Madro-Tertiary geoflora during the Cenozoic era (Axelrod 1958). The two types separated during the mid-Pliocene Epoch in response to major topographic-climatic changes, which produced the present climates in both ecosystems. Greatest climatic differences between the two regions are in amount and distribution of precipitation. Arizona chaparral receives about 400-600 mm precipitation annually, distributed bimodally with approximately 55 percent occurring during the winter from November through April, and the remaining 45 percent during summer convection storms in July through September (Hibbert and others 1974). California chaparral developed under a Mediterranean-type climate, which receives about 660-915 mm precipitation annually, primarily during the cool winters, the summers being hot and dry (Mooney and Parsons 1973). This difference in climate is reflected in the growth patterns of the two chaparral ecosystems. Growth in California chaparral occurs primarily during winter and spring, contrasted to a spring and summer growing season for Arizona chaparral. Differences in plant genera and species also exist between Arizona and California chaparral. Arizona chaparral is devoid of the "soft chaparral" or coastal chaparral communities [composed of black sage (*Salvia* spp.) and buckwheat (*Eriogonum* spp.)] and chamise chaparral (*Adenostoma* spp.), both of which are common in California (Horton 1941). Several genera, however, are common to both Arizona and California [e.x.: oak (*Quercus*), ceanothus (*Ceanothus*), and mountainmahogany (*Cercocarpus*)]. Several species found in the Lower Sonoran desert--catclaw acacia (*Acacia*

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[1]Presented at the Symposium on Fire and Watershed Management, October 26-28, 1988, Sacramento, California.

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greggi Gray), catclaw mimosa (Mimosa biuncifera Benth), mesquite (Prosopis juliflora Swartz DC)--extend into the Arizona chaparral (Knipe and others 1979). Also, postfire successional patterns differ slightly between the two ecosystems in that dense stands of short-lived deervetches (Lotus spp.) and lupines (Lupinus spp.) are sometimes present in immediate postfire seral stages in California chaparral, but are absent in Arizona.

Comparative information on aboveground biomass and soil nutrients in Arizona and California chaparral is sketchy, although published data show similar amounts of total nitrogen (N) and phosphorus (P) in litter and soils, indicating both ecosystems have adapted similarly to edaphic and climatic limitations of their respective environments (DeBano and Conrad 1978; Mooney and Rundel 1979; Pase 1972; DeBano, unpublished data[3]). Comparative data available on readily extractable ammonia- and nitrate-N in unburned soils show the upper soil layers under Arizona chaparral contain higher concentrations of ammonia-N (5-20 •g/g) than California chaparral (1-2 •g/gm), but both ecosystems containing similar nitrate-N (1-2 •g/gm) (Christensen and Muller 1975; DeBano and others 1979a; DeBano, unpublished data[3]). Nitrogen and phosphorus are limited in both ecosystems, and vegetation growth responds to these fertilizers (Hellmers and others 1955; DeBano, unpublished data[3]).

Although differences in vegetation composition, successional patterns, climate, and soil nutrients exist between Arizona and California chaparral, it is unlikely that these differences substantially affect the general relationships and conclusions concerning fire effects presented below. Similarity of fire behavior probably overwhelms any inherent differences present in the two ecosystems. Known quantitative differences between the two systems will be indicated where data are available.

ASSESSING FIRE EFFECTS

Predicting fire effects in soils is a three-stage procedure; namely: (1) characterizing fire intensity, (2) relating fire intensities to soil heating, and (3) predicting changes in chemical, physical, and biological soil properties in response to different soil heating regimes. Characterizing fire intensity and its relationship to soil heating will be discussed briefly, but more detail is published elsewhere (DeBano 1988).

[3]Data on file, Rocky Mountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, Tempe, Ariz.

Characterizing Fire Behavior and Intensity

Large differences in fire behavior commonly experienced between prescribed burns and wildfires in most forest ecosystems makes data on fire effects studies in forested ecosystems of limited value when predicting fire effects in chaparral. The reason for this being that wildfires in forests spread rapidly through the crowns of standing live and dead trees. As a result, large amounts of canopy (leaves, twigs, and in some case boles) are consumed along with substantial amounts of surface needles and leaf litter. This releases large amounts of thermal energy very rapidly, causing substantial soil heating. In contrast, prescribed fires in forests behave much differently, because they are designed to burn much cooler, thereby consuming only part of the surface needles and litter. These are often referred to as "cool" fires. However, fire in chaparral is carried through the shrub canopy during both wild and prescribed fires. As a result, fire intensity and the resulting soil heating during prescribed burns compared to wildfires in chaparral are not as great as occurs between these two types of fire in forests. For example, only minimal soil heating occurs during a cool burning prescribed fire in forests compared to low intensity fires in chaparral (fig. 1A, B).

Although canopy consumption occurs during prescribed burning in chaparral, fire intensities in chaparral vary considerably and, as a result, produce different amounts of soil heating (fig. 1B, C). Marginal burning conditions produce less intense fires, which consume only part of the canopy, leaving substantial amounts of unburned litter on the soil surface. Although not all the canopy may be consumed during a fire, the remaining tops will die and contribute to dead fuel loading for a future fire. Recently improved aerial ignition techniques have allowed successful prescribed burning to be done during marginal, and safer, burning conditions, which also reduces the impact of fire on the underlying soil. The availability of new research information along with these modern ignition techniques allows managers to develop burning prescriptions, which can minimize fire intensity, and thereby reduce the fire effects on chaparral soils.

Predicting Soil Heating

Fire intensity can be characterized in several ways, but those indices related to rate of combustion and amount of aboveground biomass and litter consumed during a fire are probably most applicable for assessing soil heating. Heat produced during burning is both dissipated upward into the atmosphere and radiated downward toward the soil and litter surface. If heat radiates directly on dry soil not having a litter layer, the heat will be transmitted slowly into the soil. When thick litter layers are present, secondary combustion can occur in the litter, further contributing to soil heating.

Soil heating can best be illustrated by a conceptual model depicting a soil profile being exposed to surface heating by energy radiated downward from the burning canopy. Although most of the energy generated during combustion is lost upward into the atmosphere, a small, but significant, quantity is absorbed at the soil surface and transmitted downward into the soil. It has been estimated that about 8 percent of the total energy released during a chaparral fire is transmitted into the underlying soil (DeBano 1974). Heat impinging on surface of a dry soil is transferred by particle-to-particle conduction and convection through soil pores. Heat transfer in wet soils is mainly by vaporization and condensation of water. Dry soil is an excellent insulating material, and heat is conducted into the underlying soil slowly. In contrast, wet soil conducts heat more rapidly at temperatures below the boiling point of water. Differences in heat capacity of dry and wet soil also exist, with wet soils absorbing more heat per degree of rise in temperature than dry soils, because water has a greater specific heat capacity than mineral soil.

Although abundant information is available on fire intensities in different vegetation types, only a few attempts have been made to develop mathematical models relating fire intensity to soil heating (Albini 1975; Aston and Gill 1976). These models have not been particularly successful and, as a result, semi-quantitative methods are being used instead. One such method for chaparral involves classifying fire intensity as light, moderate, or intense, based on the visual appearance of burned brush and litter (Wells and others 1979). After burning intensity has been placed in one of the above classes, soil heating can be estimated from curves developed by DeBano and others (1979b). These soil temperatures can then be used to predict changes that will be produced in different soil properties. Currently a slightly different approach is being developed for estimating N and P losses. This method is based on the relationship developed by Raison and others (1984) between nutrient loss and percent consumption of organic matter.

EFFECT OF HEATING ON SOILS

The spatial distribution of soil properties in a typical soil profile makes some properties

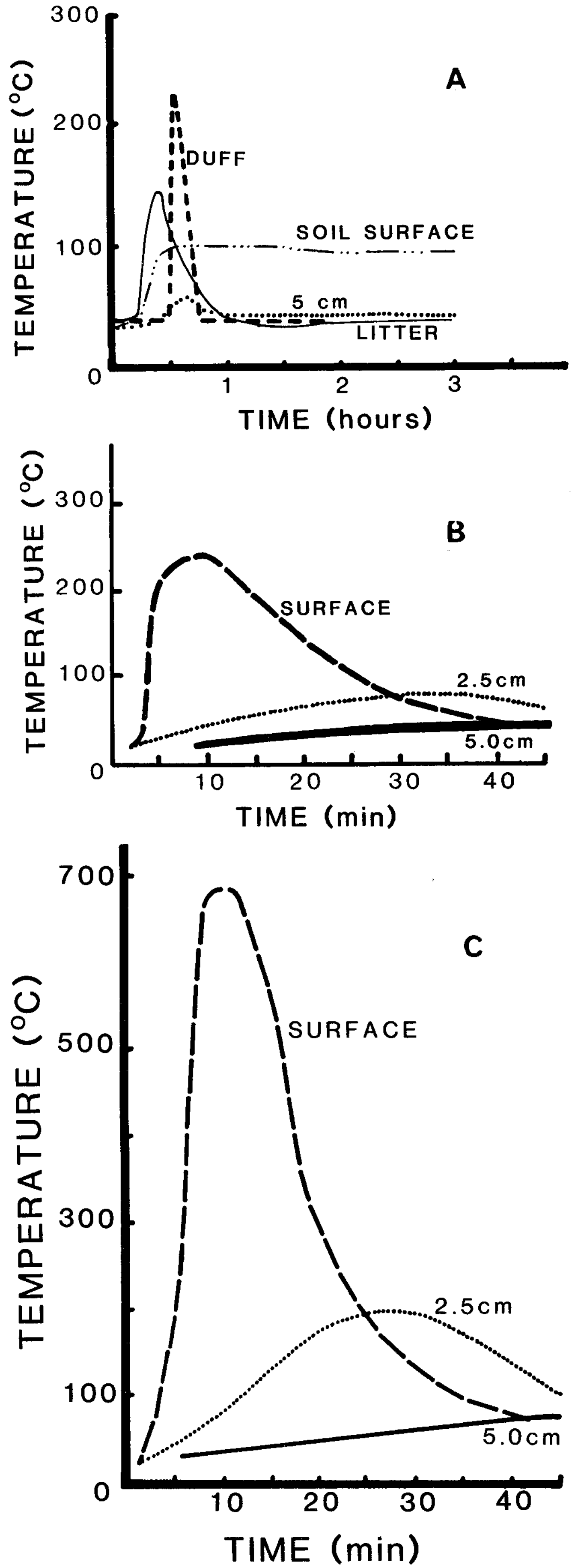

Figure 1--Soil and litter temperatures during A, a cool-burning prescribed forest fire; B, a low-intensity prescribed fire in chaparral; and C, a chaparral fire approaching wildfire intensities (DeBano 1979).

more vulnerable to surface heating than others. For example, living organisms and soil organic matter are concentrated at or near the soil surface and decrease exponentially with depth. Therefore, organic matter is directly exposed to heat radiated downward during a fire. As a result, soil chemical, physical, and microbiological properties most strongly related to organic matter are most susceptible to being changed by soil heating. For example, soil structure, cation exchange capacity, available nutrients, and microbial activity are all highly dependent upon organic matter, which begins changing chemically when heated to 200° C and is completely destroyed at 450° C (Hosking 1938). Cation exchange capacity of a soil depends not only on humus, but also on clay colloids. Humus is concentrated at, or near, the soil surface and thereby directly exposed to heating. In contrast, clay formed by pedogenic processes is usually concentrated deeper in the soil profile, although sometimes clays are found near the surface. Soil organic matter is also important for maintaining aggregate stability and soil structure, which in turn affects infiltration and other hydrologic properties of soils such as water repellency. Soil chemical properties most readily affected are total and available forms of N, P. and sulfur (S); and cation exchange capacity. Microbiological properties regulating input, loss, and availability of nutrients may also be significantly changed by soil heating. These include organic matter decomposition, N-fixation, and nitrification.

Soil Chemical Properties and Plant Nutrients

Fire acts as a rapid mineralizing agent that releases plant nutrients from organic fuel materials during combustion and deposits them in a highly available form in the ash on the soil surface (St. John and Rundel 1976). Large amounts of some nutrients such as N, S, and P can be volatilized during a fire (Raison and others 1984; Tiedemann 1987). Over 150 kg/ha of total N has been reported lost during a chaparral fire (DeBano and Conrad 1978). Cations such as calcium (Ca), magnesium (Mg), potassium (K), and sodium (Na) are not volatilized, although small amounts can be transferred from the site in smoke (Clayton 1976).

Although large amounts of total N and P are lost during burning, extractable ammonium-N and P are increased in the ash and upper soil layers (Christensen and Muller 1975; DeBano and others 1979a). Ammonium-N is highest immediately after burning, but is quickly converted to nitrate-N by nitrification. A study in Arizona showed ammonium-N in surface 0-2 cm layer was increased from 6 to 60 •g/g, nitrate-N remained at about 2 •g/g, and extractable P increased from 6 to 16 •g/g during a prescribed fire (DeBano, unpublished data[3]). Similar responses have been measured in California chaparral, but the levels of ammonium-N and nitrate-N are generally less (Christensen and Muller 1975; DeBano and others 1979a). Available N and P produced during the fire increase the supply of available nutrient in the soil until plants become established and are able to utilize them. The elevated levels of available N and P found immediately after burning decrease to prefire levels in about 1 year.

Soil Physical Properties

Soil physical properties dependent on organic matter, such as soil structure and infiltration, are directly affected by fire. The destruction of soil structure reduces pore size and restricts infiltration. More importantly, burning decreases soil wettability (DeBano 1981). During fires, organic matter in the litter and upper soil layers is volatilized. Most of the volatilized organic matter is lost upward in the smoke, but a small amount moves downward into the soil and condenses to form a water-repellent layer that impedes infiltration. Downward movement of vaporized materials in soil occurs in response to steep temperature gradients present in the surface 5 cm of soil. The degree of water repellency formed depends on the steepness of temperature gradients near the soil surface, soil water content, and soil physical properties. For example, coarse-textured soils are more susceptible to heat-induced water repellency than finer textured clay soils. Water-repellent layers can totally restrict infiltration and produce runoff and erosion during the first rainy season following fire (DeBano 1981; Wells 1981).

Soil Microbiology and Seed Mortality

Soil heating directly affects microorganisms by either killing them directly or altering their reproductive capabilities. Indirectly, soil heating alters organic matter, increasing nutrient availability and stimulating microbial growth. Although the relationship between soil heating and microbial populations in soil is complex, it appears that duration of heating, maximum temperatures, and soil water all affect microbial responses (Dunn and others 1979, 1985). Microbial groups differ significantly in their sensitivity to temperature; they can be ranked in order of decreasing sensitivity as fungi>nitrite oxidizers>heterotrophic bacteria (Dunn and others 1985). Nitrifying bacteria appear to be particularly sensitive to soil heating; even the most resistant *Nitrosomonas* bacteria can be killed in dry soil at 140° C and in wet soil at 75° C (Dunn and others 1979). Physiologically active populations of microorganisms in moist soil are more sensitive than dormant populations in dry soil.

Soil heating during a fire affects postfire germination of seeds in the litter and upper soil layers. Germination of seeds produced by some chaparral brush species is stimulated by elevated temperatures during fire (Keeley 1987). Both maximum temperatures and time of exposure affect survival and germination of ceanothus seeds (Barro and Poth 1988). As for microorganisms, lethal temperatures for seeds are lower in moist soils than in dry.

MANAGEMENT IMPLICATIONS

Postfire rehabilitation needs to address both short- and long-term fire effects on total nutrient losses (particularly N), changes in nutrient availability, decreased infiltration rates, and erosion.

Nutrient Losses

Although several plant nutrients are lost directly during combustion and by erosion following fire, N is most important because larger amounts are lost, and it is the most limiting nutrient in chaparral ecosystems (Hellmers et al. 1955). Therefore, postfire rehabilitation planning must consider mechanisms available for replenishing N to assure long-term productivity.

The amount of N lost during burning will vary depending upon the amount of aboveground biomass, litter, and soil organic matter pyrolyzed during a fire. Studies in California chaparral showed that 150 kg/ha of N were lost by volatilization and an additional 15 kg/ha by erosion after fire (DeBano and Conrad 1976, 1978). This loss represented about 11 percent of the N in plants, litter, and upper 10 cm of soil before burning. If this amount had been lost from the site during each fire over the many millennia during which chaparral vegetation has been evolving, and no mechanism existed for replenishing it, then the site would be completely devoid of N.

Several mechanisms are available for restoring N lost during a fire. These include input by bulk precipitation and N-fixing plants and microorganisms. Bulk precipitation is estimated to restore about 1.5 kg/ha annually, which is not sufficient to restore the N lost if it is assumed chaparral burns every 25 to 35 years (Ellis and others 1983). The annual input of N may be substantially greater in localized areas having large amounts of airborne N pollutants present such as the Los Angeles Basin. For example, Riggan and others (1985) found annual inputs of 23.3 and 8.2 kg/ha of N as canopy throughfall and bulk precipitation, respectively.

An important source of N replenishment appears to be by N-fixing microorganisms. It was initially thought that short-lived, nodulated legumes--deervetches and lupines--may replace a large amount of N lost during fire (DeBano and Conrad 1978). However, recent estimates of N-input by these legumes was only about one-half that gained from precipitation (Poth and others 1988). Nitrogen fixation by asymbiotic organisms is also low, amounting to about 1 kg/ha annually. It now appears that the most likely source of ecosystem N is biological N-fixation by actinomycete-nodulated shrubs such as birchleaf mountainmahogany and perhaps ceanothus (*Ceanothus leucodermis*). However, a paradox still exists regarding N loss during a fire, production of highly available N, and the role of N-fixing legumes in restoring N after fire. Although large amounts of total N are lost, high concentrations of available N are present on the soil surface immediately following burning. The problem is further complicated because N-fixation by legumes is suppressed by high concentrations of available N. Furthermore, poorly aerated soil may lead to denitrification, which further increases N losses resulting from fire. Therefore, it becomes important in postfire planning to favor establishment of N-fixing shrubs, which can effectively fix N after the high levels of available N released during the fire have been immobilized. Both ammonium-N and nitrate-N generally drop to prefire levels within a year following fire.

Another postfire rehabilitation treatment that can affect N-fixation is competition among introduced plants used for erosion control, and native plants. For example, reseeding annual grasses may compete with either short-lived legumes immediately after fire or, more importantly, with seedling establishment of longer term N-fixers--mountainmahogany and ceanothus--or even sprouting species (Conrad and DeBano 1974). Undesirable competition by reseeded grasses after fire would probably affect N replenishment in California chaparral more adversely than in Arizona because short-lived legumes are absent immediately after fire in Arizona. Longer term effects of grass on shrubs should be similar in the two ecosystems because both ecosystems contain both mountainmahogany and ceanothus.

Nutrient Availability

The question frequently arises whether there is a need to fertilize as part of postfire rehabilitation. Fertility assessment trials show burned soils have a greater available N supply than unburned soils (Vlamis and others 1955). Similarly, N fertilizer responses were not detectable on field plots immediately following fire (DeBano and Conrad 1974). Postfire responses to P fertilizers are more variable because some soils can rapidly fix available P produced during burning (Vlamis and others 1955; DeBano and Klopatek 1988). The preponderance of research results seems to indicate that fertilization is probably not a desirable treatment immediately following burning. In fact, fertilization may have a depressing effect on N fixation because additional amounts of highly available N are added to already high levels produced by burning. Also, the high levels of available N following fire could lead to increased denitrification in poorly aerated soils. The advisability of P fertilization is less clear but it may, be of little advantage in those soils that irreversibly fix available P. In summary, fertilizing in the "ash" is not a recommended postfire treatment, and fertilizers should not be applied for at least 1 year following burning.

Erosion

There are limited opportunities for preventing, or reducing, erosion on chaparral soils burned during wildfire conditions. Grass reseeding has been widely used in postfire rehabilitation. The usefulness of ryegrass reseeding for postfire erosion reduction has not been clearly established because of the limited opportunities for grass to become established before active erosion occurs during the first year following fire. It is also extremely difficult to design studies clarifying the relationship between grass establishment and erosion because of the high variation encountered under field conditions (Barro and Conard 1987). Ryegrass competition may also indirectly interfere with establishing native plants following fire and, as a result, contribute to long-term erosion. Establishment of a dense grass cover on burned sites may also increase the volume of fine dead fuels by the end of the first growing season, thereby making these areas more susceptible to ignition and early reburns.

The judicious use of prescribed fire could potentially provide a viable technique for minimizing erosion resulting from wildfires. Prescribed fire is being advocated as a tool in southern California for reducing wildfire severity by creating uneven-age stands that break up continuous fuel loads necessary for sustaining large-scale wildfires (Florence 1987). Replacing intense, widespread wildfires with cooler burning prescribed fires would reduce fire impacts on soils. Not only would plant nutrient loss be reduced, but burning under cooler conditions and over moist soils would reduce the severity of water repellency and postfire erosion (DeBano 1981). This management concept is also consistent with developing brush-grass mosaics for water augmentation in Arizona chaparral (Bolander 1982).

CONCLUDING COMMENTS

Both wild and prescribed fires occur frequently in Arizona and California chaparral. Although these two ecosystems evolved into different floristic entities, they share many common attributes in their response to fire. From limited comparative data for Arizona and California, it appears that fire has a similar effect on physical, chemical, and biological soil properties in both ecosystems.

Soil chemical, physical, and microbiological properties most strongly interrelated with organic matter are most susceptible to being changed by soil heating. Soil structure, cation exchange capacity, available nutrients, and microbial activity are all highly dependent upon organic matter, which is completely destroyed at 450° C. Fire also acts as a rapid mineralizing agent releasing plant nutrients from organic fuels during combustion and depositing them in a highly available form on the soil surface. Substantial amounts of N, S, and P can be lost during combustion. Replenishment of N losses is an important part of postfire rehabilitation planning. Treatments interfering with postfire establishment of N-fixing plants should be avoided; particularly important is the competition between reseeded grasses and naturally occurring N-fixing plants.

Burning increases the availability of most plant nutrients. Although total N is lost, available ammonium-N and P increase substantially as a result of burning. High levels of available plant nutrients immediately after burning make fertilizing for at least 1 year following fire impractical.

In the final analysis, the judicious use of prescribed fire has an important role in managing chaparral ecosystems in both Arizona and California. Prescribed fire can be used as a technique for reducing the probability of catastrophic wildfires. Improved wildlife habitat, better access, and increased water production also result from well-planned prescribed burning programs. Certain precautions must be taken during postfire treatments, however, to assure the continued long-term productivity of these ecosystems.

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Soil Hydraulic Characteristics of a Small Southwest Oregon Watershed Following High-Intensity Wildfires[1]

David S. Parks and Terrance W. Cundy[2]

Abstract: The Angel Fire of September, 1987 caused extensive damage to second growth forest in the south fork drainage of Cow Creek, 55 km northeast of Grant's Pass, Oregon, USA. The fire was characterized by a high-intensity burn over areas of steep topography. The areal distribution of soil hydraulic properties in a small, tributary watershed following high-intensity wildfire is examined using tests of infiltration capacity, saturated hydraulic conductivity, and soil moisture characteristics. Also, measures of soil water-repellency are determined. Soil hydraulic properties are evaluated for logged and forested slopes up to 30 degrees. Results indicate a relatively small effect of high-intensity wildfire on the generation of water-repellent soils and the hydrologic response of this watershed.

This study characterized the soil hydraulic properties of a small watershed in southwest Oregon that experienced high intensity wildfire. Of particular interest is the degree to which the wildfire produced water-repellent soils.

STUDY SITE

The study site (fig. 1) is in southwest Oregon, 55 km northeast of Grant's Pass. It consists of a 1.3 km^2, first and second-order drainage on the south fork of Cow Creek. The site ranges in elevation between 975 and 1340 m with maximum slope angles approaching 30 degrees.

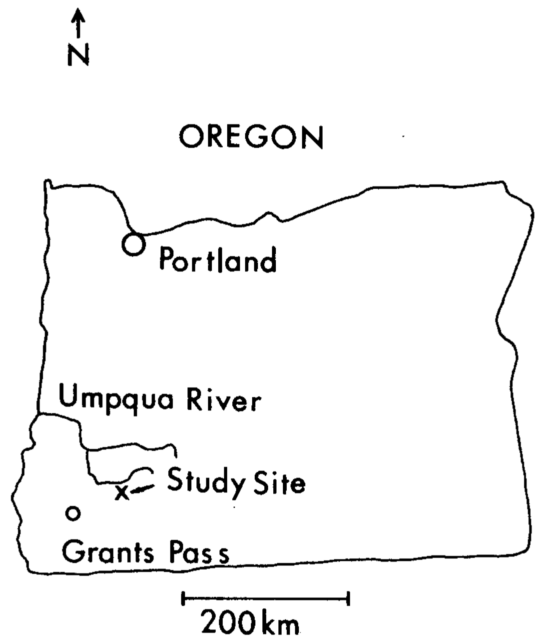

Figure 1--Study Site Location

Vegetation within the study area is Douglas fir and mixed pine forest with an understory of grasses, ferns, forbs, and shrubs. Vegetation on the study site has been largely removed by road building, logging, and wildfire.

Soils in the study basin can generally be described as stony clay-loam, derived from moderately competent serpentine bedrock. In forested areas, the soil is covered with an organic litterlayer of 1.5 to 7.5 cm.

SAMPLING PLAN

Soil samples were taken from four areas (Fig. 2), consisting of a forested erosion pin plot, a logged erosion pin plot, an undisturbed forested control area and an area of mixed landcover types. All sites except the control site were burned by wildfire in September 1987; fieldwork was conducted February 25-28, 1988.

Field inspection of the soils showed no obvious hydrophobic layer; accordingly, sampling was confined to the upper 10 cm of the soil profile.

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[1]Presented at the Symposium on Fire and Watershed Management, October 26-28, 1988, Sacramento, California.

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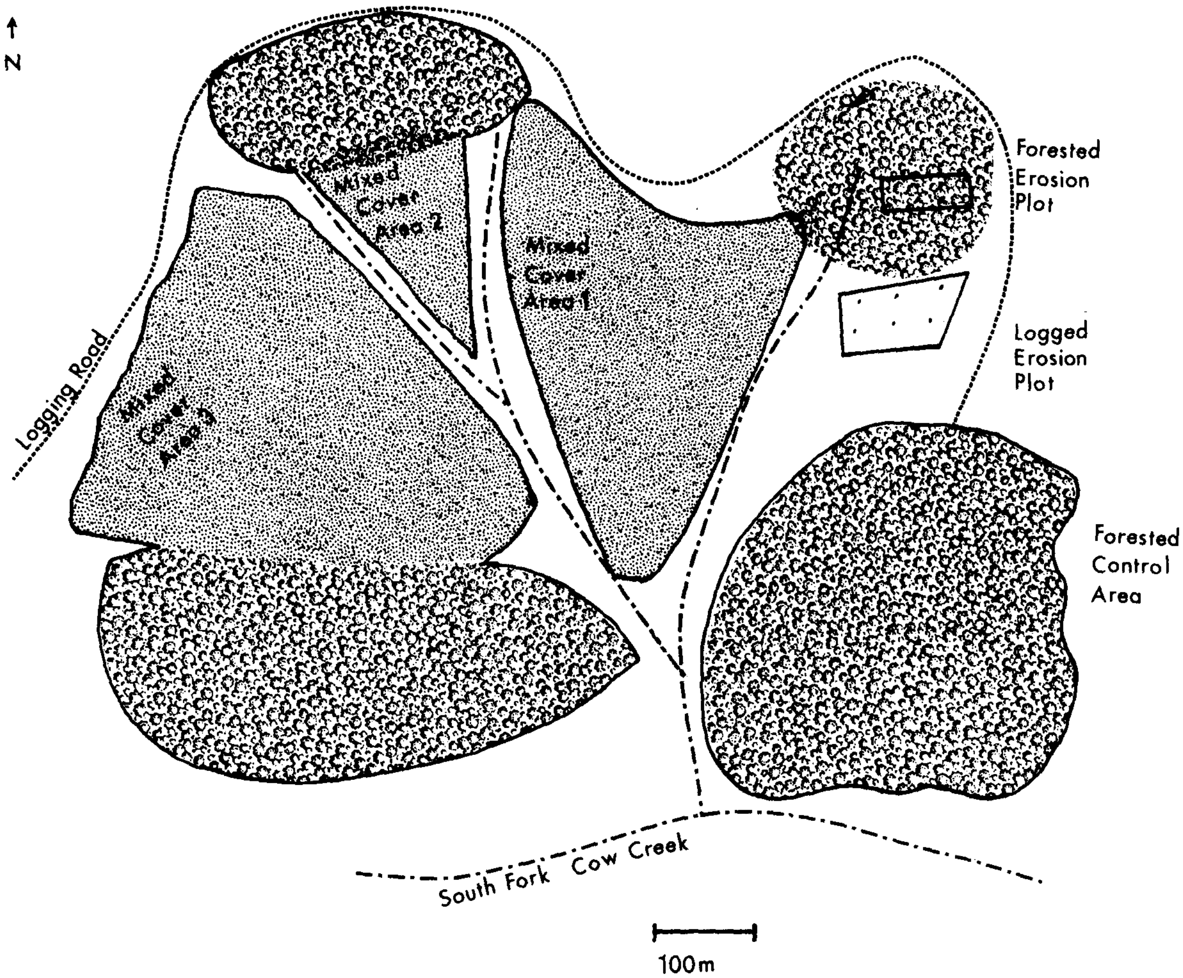

Figure 2--Study basin diagram showing sampling areas.

The two erosion pin plots were sampled on their perimeter at 10-m intervals. The control site was randomly sampled, as was the mixed landcover area.

The soil sampling procedure used a gravity soil corer that retrieves a soil cylinder of 68.7 cm^3 (5.4 cm diameter x 3 cm height). Infiltrometer measurements were limited to the two erosion pin plots.

METHODS OF ANALYSIS

Field Measurements

Infiltration capacity was measured using a single-ring ponding infiltrometer (Hills 1970). The ring was 10.2 cm in diameter and a constant head of 1.27 cm of water was used. Field data consist of time (t) versus cumulative infiltration (F) in cm.

Laboratory Measurements

Parameters measured by laboratory experiment included bulk density, saturated water content, saturated hydraulic conductivity, water drop penetration, and soil moisture-capillary pressure changes.

Bulk density (gm/cm^3) was determined by drying the cores at 105° C for 24 hours and weighing. Bulk soil volume of the samples was 68.7 cm^3.

Saturated water content was determined by saturating the soil cores with water for 24 hours. The cores were then removed from the water, allowed to drain for 30 minutes, and weighed. Moisture contents are reported as volume of water per bulk volume of soil.

Saturated hydraulic conductivity (cm/hr) was determined using a constant head device with 3 cm of water depth.

The desorption soil moisture-capillary pressure curves were determined with a pressure plate. Soil water content at 0, 0.1, 0.2, 0.3, 0.5, 1, 3, 10 and 15 bars were determined by progressively weighing and drying the cores. Data (fig.3) are reported as volume of water per volume of bulk soil versus pressure.

Water drop penetration is a test of the water repellency of soils. Letey (1968) describes the test, which consists of applying a small quantity of water to the soil and measuring the time until the water is absorbed. We conducted the test using oven-dried soils and applying 1 cm^3 of water. Absorption times are reported in seconds.

RESULTS AND CONCLUSIONS

Results of the laboratory analyses are shown in table 1. Values for all areas and transects sampled were compared statistically to those from the control plot, using a two-sample t-test for means and an F-test for variances (Snedecor and Cochran 1967). As can be seen from table 1, there are few statistically significant differences. The majority of the significant differences are in variances and seem to reflect an overall homogenization of burned sites compared to the unburned control; in nearly all cases the variance of properties measured in the burned sites was less than that measured on the control.

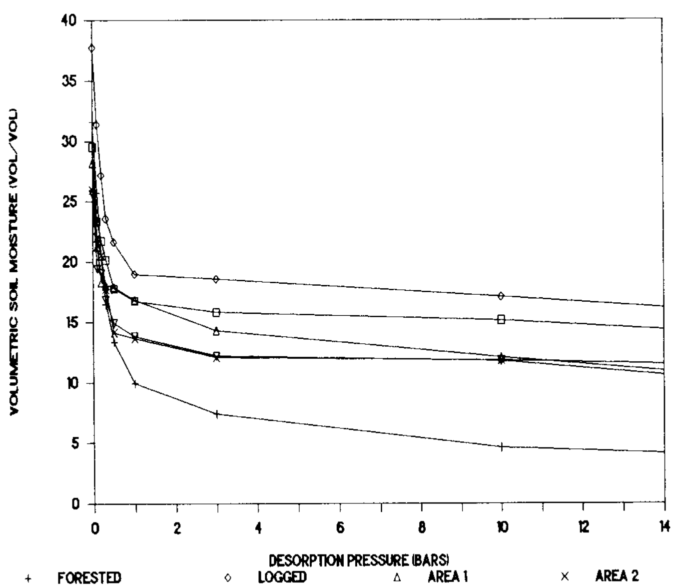

Figure 3-- Median capillary pressure changes by location

Control Area

Saturated hydraulic conductivities measured in this area are the highest measured in the study basin with a mean of 78.9 cm/hr. These data also point out the extreme variation characteristic of this property; the coefficent of variation is near unity.

Bulk density values for the control area are the highest measured in the basin with an average of 1.04 gm/cm ^{3}, though only slightly larger than the other areas sampled. Saturated water contents for the control area had a mean value of 41.4, near the middle of the values for the other areas, and a standard deviation of 8.65, the second highest value overall.

Soil water-capillary pressure curve data measured for the control area show a relatively strong ability of the soil to hold water under tension, and may be a result of the high clay content of the soil underlying the surface organic layer in this area. Statistics of water drop penetration times for the control area are found in table 1. While these values are not high when compared to those for extremely water-repellent soils, they do indicate a moderate degree of water repellency (DeBano 1981).

The infiltration capacity of the control area exceeds rainfall intensities and should yield little surface runoff.

Surface erosion on the control area should be minimal and most likely be a result of windthrow and resulting soil disturbance. Landsliding may contribute sediment to streams if the subsurface flow of water is sufficient to cause saturation of the soil mass.

Forested Erosion Plot

Results of the field infiltration tests are given in table 1. The infiltration rates are generally quite high (150+ cm/hr for the short times tested) and quite variable between runs (infiltration capacities at different points for the same time vary by a factor of 2 to 5). Excavation around the infiltrometers following the test showed the flow from the infiltrometer was largely downhill and occurred above a clayey horizon found at an approximated depth of 3 to 9 cm.

Hydraulic conductivity is high and extremely variable (nearly two orders of magnitude); this is consistent with the ring infiltration measurements made on the site and the hydraulic conductivities from the control site. While the hydraulic conductivities are approximately one-third less on this plot than the control plot, they are not statistically different than

Table 1--Summary statistics by sample location

Sample sites	[1]N	[2]Ks	[3]Bd	[4]SWC	[5]IR	[6]WDPT
		cm/hr	gm/cm^3	pct.vol	cm/hr	sec
Control	10	[7]78.9	1.04	41.4	N.A.	164
		[8]78.8	.177	8.65	N.A.	290
Forested	26	55.2	.921*	50.0*	209	2
		45.5*	.137*	6.90	166	.385*
Logged	25	33.7	1.03	51.1*	205	80
		34.3*	.102*	9.21	126	180
Area #1	15	37.7	.925	36.6	N.A.	300
		23.4*	.074*	8.27	N.A.	953*
Area #2	7	34.1	1.03	35.3	N.A.	7
		16.0*	.030*	4.66	N.A.	12*
Area #3	9	31.4	1.02	34.0	N.A.	405
		11.8*	.027*	7.00	N.A.	1200*

[1]Number of samples measured
[2]Saturated Hydraulic Conductivity
[3]Bulk Density
[4]Saturated Water Content
[5]Infiltration Rate
[6]Water Drop Penetration Time
[7]Sample Average,
[8]Standard Deviation
* = indicates significant difference than control value at alpha = 0.05

the control plot, and still larger than rainfall intensities.

Bulk densities are low, and saturated moisture contents are high, reflecting the open structure typical of forest soils. The saturated moisture content values are significantly different from the control plot values.

Statistics of water drop penetration are shown in table 1. Penetration times are nearly instantaneous, indicating the absence of water repellency.

The results above indicate that the runoff processes on the forested plot will probably not be significantly altered by the fire. Infiltration capacities and hydraulic conductivities are high, leading to the conclusion that the system is dominated by subsurface flow; this is typical of forested sites and identical to the conclusion for the control site. Overland flow, if it occurs, would be by saturation of the soil.

Erosion on this plot should occur as some surface wash and shallow piping if saturation overland flow occurs. Since this plot still had significant organic cover we expect raindrop splash and surface sealing to be unimportant.

<u>Loaned Erosion Plot</u>

Results of the field infiltration tests for the logged erosion plot (table 1) are almost identical to the results for the forested plot discussed above, indicating that little surface runoff is to be expected.

Saturated hydraulic conductivities measured on the logged plot (table 1) are lower than the control plot, though not statistically significant. While these conductivities are well above expected rainfall intensities, they possibly indicate an effect of log skidding. Bulk density of the logged plot falls between the forested plot and the control area. Saturated water contents for the logged plot are significantly higher than the control plot.

Soil moisture-capillary pressure curve data for the logged plot show the highest water retention of all areas. This may be a result of the surface disturbance by log skidding and the exposure of the clayey subsoil.

Water drop penetration times for the logged erosion plot are higher than the forested erosion plot but lower than the control area. According to DeBano (1981) this soil would be classified as moderately water repellent, like that of the control area.

Results obtained for the logged erosion plot indicate that this area has been moderately affected by logging and fire. The expected runoff response of this plot is likely to be subsurface although some surface runoff may occur where the clayey subsoil is exposed. No organic horizon is found in this area, and erosion from raindrop splash is expected. This may in turn cause surface sealing and further surface runoff.

Area Transects

The soils data for the three transects are very similar to those for the other plots; as part of the overall logged and burned area they exhibit mean saturated hydraulic conductivity values nearly identical to those for the logged erosion pin plot.

The saturated water contents are the lowest reported. The water penetration time data show significant variation both within and between transects. The within-transect variation might be explained by the disturbance associated with logging and the removal and redistribution of organic matter. The between-area variation may reflect the differences in fire intensity over the watershed. For example, area 2, which has the smallest penetration times, appears to have been only lightly burned. Area 1 appeared in the field to have been heavily burned. Area 3 appeared to have areas of both heavy and light burning.

Again using the classification scheme of DeBano (1981), soils in areas 1 and 3 would be considered moderately water repellent, while those in area 2 would be considered slightly repellent.

The results above indicate that soils in areas 1 and 3 are somewhat water repellent. This condition, with the removal of surface organic matter, may lead to some Horton overland flow in response to high-intensity storms falling on dry soils. The hydraulic conductivities are still high compared to rainfall rates, indicating that when the soils are wet, subsurface flow paths will dominate.

Erosion on the area areas will likely be a mix of raindrop splash and sheetwash during the summer. Landsliding may still be important during winter on steeper parts of the watershed.

SUMMARY

A study of soil hydraulic properties was conducted on a small watershed in southwest Oregon to evaluate the effects of wildfire on hydrologic response and erosion.

Results of the analyses indicate a small effect of high intensity fire in causing some moderately water repellent soils over some areas of the watershed. This effect will most likely be seen as some sheetwash during summer periods of high intensity rain on dry soils. Runoff response during wet periods will likely be dominated by subsurface flow paths.

ACKNOWLEDGMENTS

We thank Jack Schimdt, Holly Martinson and Garry Gallino, Geological Survey, U.S. Department of the Interior, for their assistance with the development of our sampling scheme and for logistical support in the field; and Doug Tompkins, Middlebury College, Middlebury, Vermont, for his assistance in the field. This study was supported by Grant 191336, Geological Survey, U.S. Department of Interior.

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Frequency of Floods from a Burned Chaparral Watershed[1]

Iraj Nasseri[2]

Abstract: Effects of brush fire on hydrologic characteristics of chaparral watersheds were analyzed. An unburned chaparral produces moderate surface runoff. The vegetation promotes infiltration by retarding the runoff and providing temporary storage during intense rainfall. The hydrologic characteristics of chaparral watershed, however, are drastically changed by fires. The high rate of runoff following brush fires may result from the combined effects of denudation and formation of a water-repellent soil layer beneath the ground surface. This layer greatly decreases infiltration rates and reduces the hydrologically active portion of the watershed. Infiltrometer tests were performed on burned and unburned watersheds with similar soil types. The test results for the selected sites showed that for simulated rainfall intensities of one-inch per hour or more, the average ratio of runoff rate to rainfall intensity could be two times as great for the burned as for the unburned condition. To simulate floods following a brush fire, the Stanford Watershed Model was calibrated to a burned watershed using the hydrologic data of the postfire period. The floods were simulated by postulating scenarios that historical storms may occur following a brush fire. The study showed that the moderate storms may produce floods of considerable magnitude under a burned condition.

[1]Presented at the Symposium on Fire and Watershed Management, October 26-29, 1988, Sacramento, California.

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Chaparral watersheds in Southern California burn as often as every 30 years (Muller and others 1968). Fire suppression efforts have had partial success in containing the periodic intense wildfires that occur, but the number of fires and the total acreage burned annually remain quite high. The number of fires and the burned acreage for Los Angeles County within the past five years are shown below:

Year:	Number of Fires	Burned areas (acres)[1]
1983	32	3,150
1984	22	17,400
1985	36	9,560
1986	47	10,909
1987	136	12,921

[1]Acre = .405 hectare

An unburned chaparral watershed generally produces moderate surface runoff. The vegetation promotes infiltration by retarding the runoff and providing temporary storage during intense rainfall. High infiltration and the retention capacity of chaparral leave little water available for surface runoff. The hydrologic characteristics of chaparral watersheds, however, are drastically changed by fires. The high rate of runoff following brush fires in the chaparral watershed is attributed to the combined effects of denudation and formation of a water-repellent soil layer beneath the ground surface. This layer greatly decreases infiltration rates and reduces the hydrologically active portion of the watershed from a meter or more to a thickness to only a few centimeters (DeBano and others 1979).

RUNOFF CHARACTERISTICS OF A BURNED WATERSHED

To study the effects of a brush fire on the rate of surface runoff, infiltrometer tests were performed on selected sites of the watershed in La Canada burned by the Crest fire on January 1984. The surface runoff was produced over a controlled plot by simulating rainfall of different intensities. The runoff rates were measured and expressed in terms of runoff coefficient defined as the ratio of runoff rate to rainfall intensity. These tests were repeated on similar soil types in the same area under unburned conditions. In the plot of two sets of runoff coefficients against rainfall intensity (fig. 1), the difference between the two sets of runoff coefficients is quite significant. For rainfall intensities of 1 inch per hour or more, the average runoff coefficients may be two times as great for the burned as for the unburned condition.

To study the hydrologic characteristics of a burned watershed, the Santa Anita Dam watershed with a drainage area of 10.8 square miles (27.47 Km2) and a tributary to the Los Angeles River was selected. From December 27, 1953 to January 3, 1954, the disastrous

Table 1 - - Comparison of historical storms with the postfire storm of January 19, 1954.

Storm	Maximum intensities	Storm rainfall	Peaks	Volume of runoff
	in./hr.	in.	cfs	ac-ft.
2-2-36	.76	5.39	185	112
1-7-40	.75	4.63	385	128
1-19-54	.89	5.46	1610	540

Table 2 - - Comparison of historical storms with the postfire storm of January 24, 1954.

Storm	Maximum intensities	Storm rainfall	Peaks	Volume of runoff
	in./hr.	in.	cfs	ac-ft.
12-26-36	1.34	6.42	265	241
11-11-49	.98	6.35	62	5
1-24-54	.83	7.83	1415	530

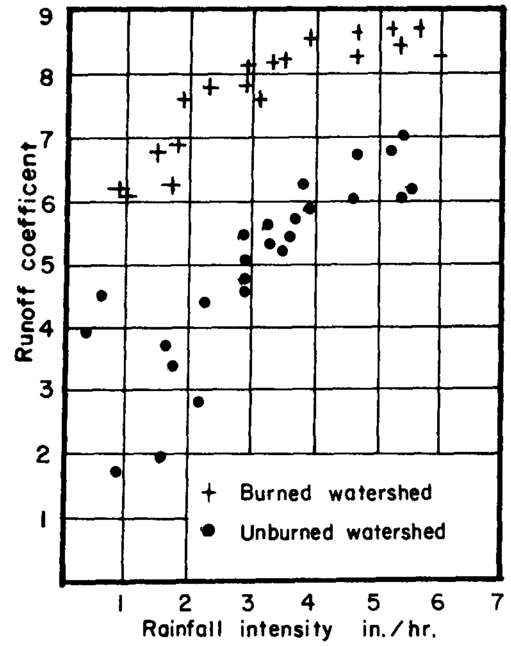

Figure 1 - - Runoff Coefficients under burned and unburned watersheds.

Monrovia peak fire, in the San Gabriel Mountains, burned 97 percent of the drainage area. This nearly complete burn, coupled with relatively good controls and records at the dam site, set the stage for obtaining data on the runoff following a brush fire.

On January 18-19, 1954, a storm produced water and debris flow on the watershed. A week later, on January 24-25, 1954, a second storm also produced water and debris flow, although of smaller magnitude. These two storms were of volume and range of intensities which had occurred in the past, so that some valid comparisons could be made under burned and unburned conditions (tables 1 and 2). The rainfall distributions and the hydrographs produced by the postfire storms of January 1954 and the comparable storms are shown in figures 2 and 3. The comparison of peak flows shows that a burned watershed may produce a peak flow several times greater than that of an unburned watershed.

<u>Hydrologic Modeling of a Burned Watershed</u>

To simulate major floods following the brush fires, the Stanford Watershed Model (Crawford and Linsley 1966) was calibrated to the Santa Anita Dam watershed using the hydrologic data of the postfire period (1953-55). The Stanford Watershed Model is a conceptual model consisting of a series of mathematical expressions which describe the hydrologic processes of a drainage basin. The model uses hourly rainfall and evapotranspiration as input data. Interception, surface retention, infiltration, overland flow, interflow, groundwater flow, and soil moisture storage are simulated to calculate inflow to the channel, and routing is used to simulate the channel system. The model is calibrated by trial until the observed flows are reproduced adequately. Three recording rain gages, one stream gage, and one evaporation station were used in the calibration of the model (fig. 4).

Several runs, each with a different set of parameters, were used to calibrate the model to the watershed under the burned conditions. The first storm following the Monrovia peak fire produced debris flow and surface runoff. Since the model should be calibrated against runoff data, the first storm, which produced debris flow, was excluded from the calibration process. The parameter of the lower zone storage in the model was found to be very small for the burned watershed. This would confirm the theory of formation of a repellent soil layer in a burned watershed.

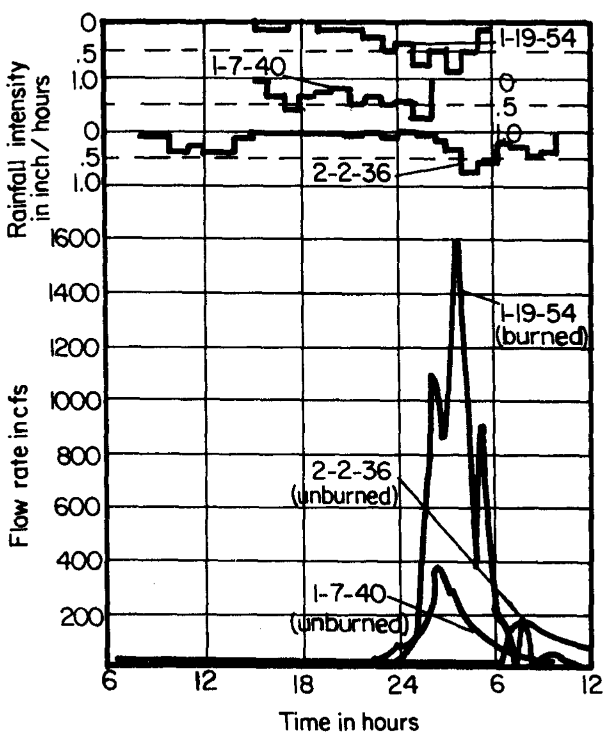

Figure 2 - - Recorded hydrographs under burned and unburned watersheds.

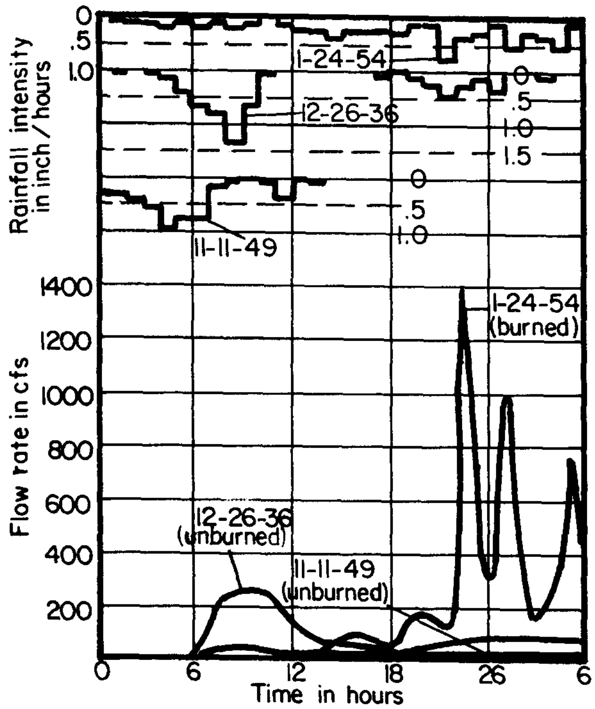

Figure 3 - - Recorded hydrographs under burned and unburned watersheds.

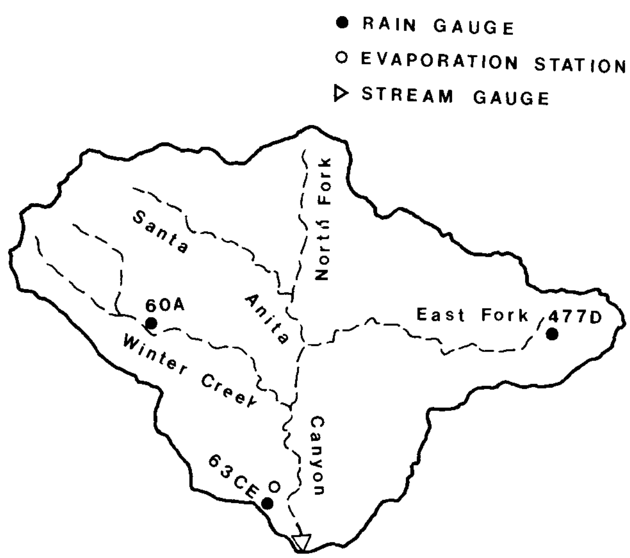

Figure 4 - - Santa Anita Dam watershed with gage location.

Frequency of Floods in a Burned Watershed

Annual peak flow data are available as far as back as 1931. The data were checked for consistency and homogeneity. The data during the recovery period (1954-1963) in which the watershed is under dynamic change were not included in flood frequency analysis. The recovery period for the burned watershed was estimated from historical fires in Los Angeles County drainage area. The Log-Pearson method was used to develop the flood frequency plot (fig. 5) for Santa Anita Dam watershed.

The Stanford Watershed Model along with the flood frequency plot can be used to predict floods from burned watersheds and their corresponding recurrence intervals. To demonstrate the application, two historical storms, one with moderate intensity and volume (storm of 1982-83), and one with extreme intensity (storm 1968-1969), were postulated to occur following a brush fire in the Santa Anita Dam watershed. Records show that these two storms have produced floods of moderate and extreme magnitudes in some areas of Los Angeles County. These two storms were used as input to the Stanford Watershed Model calibrated to the burned watershed and the floods were simulated as output from the model.

To make a probabilistic comparison, the floods resulted from above storms on burned and unburned watersheds were expressed in terms of their recurrence intervals (table 3). The results show that the magnitude of flood from the extreme storm of 1968-69 on burned watershed is not significantly different from the flood from the unburned watershed. However, the increase of six percent in the magnitude of the flood tends to change the recurrence interval from 30 years to 50 years. The moderate storm of 1982-83 appears to react more significantly on the burned watershed. The magnitude of flood from the burned watershed is increased by 200 percent and the recurrence interval changes from six years to 25 years.

Table 3 - - Comparison of floods produced under burned and unburned conditions.

Storm	Unburned watershed: Observed Floods	Unburned watershed: Return period	Burned watershed: Simulated Flows	Burned watershed: Return period
	cfs	yr.	cfs	yr.
1-25-69	5,500	30	5,850	50
3-2-83	1,200	6	3,600	25

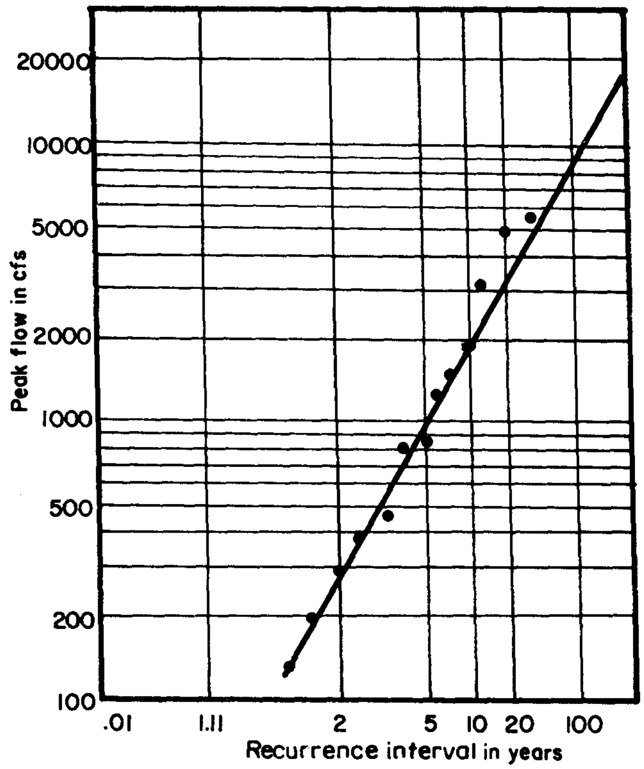

Figure 5 - - Frequency curve of annual floods for Santa Anita Dam watershed.

This study is not yet complete. Our research will continue to define the frequency characteristics of floods under burned conditions. We can draw the conclusion, however, that flood control facilities serving watersheds that experience frequent brush fires should be designed for flow characteristics under burned condition.

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Application of SAC88 to Estimating Hydrologic Effects of Fire on a Watersheds[1]

R. Larry Ferral[2]

Abstract: SAC88 is a major revision of the Sacramento Model, which was developed in 1969 with minor revisions through 1973. Two of many 1988 changes make it possible to estimate hydrologic effects of a fire in a watershed where pre-fire parameters can be calibrated or estimated: (1) Evapotranspiration, treated as extracted from six root-zone layers under pre-fire conditions, may be limited to one to five layers in the burned area; (2) An infiltration-rate limiting value, large for an unburned area, may be substantially reduced for an area where high soil temperatures and ash are thought to have created hydrophobic soil surface conditions. The application of sample rainfall sequences under pre-fire and post-fire conditions may be used to evaluate hydrologic effects of fire or other drastic changes in watershed vegetation.

THE SACRAMENTO MODEL

The Sacramento Model was developed in 1969 by National Weather Service and California Department of Water Resources hydrologists as a tool to be used in their cooperative river forecast program (Burnash and others, 1973). It is a computerized conceptual, deterministic, lumped-parameter model of watershed processes from the application of liquid water through the generation of runoff. Snow accumulation and melt processes and channel routing may be handled separately by linked models. Several minor modifications were made to this model through 1973. Since that time, it has been applied extensively by National Weather Service hydrologists and others throughout the world (Bartfeld and Taylor 1980; Burnash and Bartfeld 1980; Leader and others 1983; Twedt and others 1978).

[1] Presented at the Symposium on Fire and Watershed Management, October 26-28, 1988, Sacramento, California.

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The model includes both an impervious area that varies in size with wetness, and a permeable area. The permeable area includes five storages in two categories in the soil mantle - tension water that is filled preferentially and emptied only by evapotranspiration and free water that drains vertically and horizontally in response to gravity. The tension water storages are treated as one upper level and one lower level storage in the model, and the free water storages as one upper level and two lower level storages, with the upper level free water storage draining very rapidly both horizontally and vertically and the lower level free water storages draining at two different slower rates. Runoff is generated as direct runoff from water applied to impervious areas, subsurface drainage from each of the three free water storages, and surface runoff when the rainfall rate exceeds the rate at which water can enter the upper level storages.

SAC88 REVISIONS

SAC88, a major revision of the Sacramento Model, was begun in December 1987 (Ferral 1988). The changes made are summarized in the list that follows.

1. Thresholds that had caused abrupt transitions in the rainfall-runoff relationship have been smoothed by diverting increasing fractions of applied water into free water storages as tension water deficiencies diminish.

2. Upper-level outflow functions that drive both quick - response subsurface outflow to stream channels and percolation to deeper layers have been modified so that surface runoff is less likely to be dominant.

3. Partial area runoff caused by rainfall or snowmelt on seepage outflow areas has been modified to be controlled by outflow rates instead of by lowerzone tension water contents.

4. More layers are used in tension water accounting to allow for differing availability for evapotranspiration of near- surface and deeper soil moisture. This also allows drastic changes in effective root depth after wildfire or clear cutting to be modeled realistically. Two layers defined by the modeler are converted into six layers by the model.

5. A limiting surface infiltration rate now can be defined to account for effects of very intense rainfall or of hydrophobic soil conditions after a fire.

6. A uniformity parameter can vary the drying and wetting functions which affect runoff production.

APPLICATIONS OF THE REVISED MODEL

Changes 4 and 5 above are most relevant to the concerns of this Symposium. The Sacramento Model has been applied to dozens of small watersheds in California. It is part of the ALERT program (Automated Local Evaluation in Real Time), a cooperative National Weather Service program for local flood warnings and other purposes based mostly on radio raingages and streamgages reporting to a microcomputer that stores data as received and generates hydrologic forecasts automatically, at frequent intervals. The greatest concentration of these systems is in Southern California, where many flood-prone communities are below forested or brushcovered watersheds.

After SAC88 has been incorporated into the ALERT software and the watersheds have been recalibrated, it will be possible to make reasonable quantitative estimates of the hydrologic effects of wildfire and of subsequent revegetation. Early tests indicate that recalibration with SAC88 is easy to do. Common parameters change little from the old Sacramento Model to SAC88. A new calibration with SAC88 is no more difficult than a new calibration with the old Sacramento Model. Expert analysis will be required to estimate changes in effective rooting depth after a fire, but the model will have the capability to apply those changes to subsequent rainfall as it occurs.

Another possible use of SAC88 is to apply it to a watershed denuded by wildfire using the Extended Streamflow Prediction (ESP) mode of the National Weather Service River Forecast System (NWSRFS). This would test the effects of applying historical rainfall sequences, starting with the present day of the year and present soil moisture and rooting depth conditions, to a calibrated watershed. Such a test could estimate both the probable increases in water yield and the probability of damaging flood flows in the post-fire rainy seasons.

Hydrologic effects of proposed vegetative management schemes, such as clear cutting or brush removal, could be analyzed similarly. A drastic vegetative change over only part of a watershed could be analyzed by treating it as two watersheds, one unchanged and one modified, and apportioning the resulting streamflows.

As an example of such an analysis, this model was applied to inflow to the San Antonio Reservoir in Monterey County, California. The calibration period was October 1967 through September 1979. The watershed as calibrated has an available root-zone soil moisture storage capacity of 11.4 inches. The calibrated model was applied to the watershed for the period October 1977 through September 1979 assuming two different conditions; an undisturbed watershed and a watershed burned or clear-cut in late September 1977. The burn or clear-cut was presumed to reduce the effective root-zone soil moisture capacity subject to evapotranspiration from 11.4 inches to 4.8 inches, with only the upper three of the model's six soil moisture levels permeated by roots.

The computed mean basin precipitation for the 1977-78 water year over the 330 square mile drainage was about 29.5 inches. For the 1978-79 water year, the precipitation was about 17.5 inches. Computed runoff for the undisturbed basin condition was about 12.6 inches in 1977-78 and 4.1 inches in 1978-79. Computed runoff for the burned or clear-cut basin condition was only about 12.7 inches in 1977-78, little changed from the undisturbed condition, but 8.5 inches in 1978-79, more than double the undisturbed condition runoff. This delay in runoff effects can be explained by the large soil moisture deficit in late September 1977, and a much smaller deficit, 4.8 inches, in late September 1978, for the modified watershed. Without vegetative modification, the soil moisture deficit in late September 1978 would have been more than eleven inches.

The calibrations and analyses were done with daily rainfall data, so there was no attempt to model the possible effects of a hydrophobic layer on infiltration and runoff. Such effects would be greatest immediately after a fire, so these would be most likely to be observed in the first post-fire rainy season.

CONCLUSION

SAC88, a major new revision of the Sacramento Model, is expected to be useful in estimating the hydrologic effects of fire or other drastic vegetative changes on a watershed.

ACKNOWLEDGEMENT

I wish to thank Eric T. Strem, Senior Hydrologist and program leader for interactive calibration at the California-Nevada River Forecast Center, for applying the old Sacramento Model to calibrate all data sets used to test these revisions.

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Stream Shading, Summer Streamflow and Maximum Water Temperature Following Intense Wildfire In Headwater Streams[1]

Michael Amaranthus, Howard Jubas, and David Arthur[2]

Abstract: Adjacent headwater streams were monitored for postfire shade, summer streamflow and maximum water temperature following the 40,000 ha Silver Complex fire in southern Oregon. Average postfire shade (30 percent) for the three streams was considerably less than prefire shade (est.>90 percent). Dramatic increases in direct solar radiation resulted in large but variable increase in maximum water temperature. Increase was greatest in Stream C where temperature increased 10.0°C. Stream B increased 6.2°C. Stream A increased 3.3°C.

Variation in maximum water temperature increase was strongly correlated to summer streamflow (r^2 =0.98k and percent total streamside shade (r^2 =0.80). The greatest maximum water temperature increase was associated with lowest summer streamflow and total postfire shade. Shade from dead vegetation provided the most shade averaged for all three streams. Shade from dead vegetation was more than three times greater than shade from topography and two times greater than shade from live vegetation. Considerable loss of live vegetation and large but variable increases in maximum water temperature can accompany intense wildfire in headwater streams. Review of the Silver Fire Complex indicates, however, that less than 5 percent of the headwater streams burned in this manner.

INTRODUCTION

During August through November 1987, over 400,000 ha of forested land in northern California and southern Oregon were burned in lightning-caused fires. Included in the burned area was the 40,240 ha Silver Complex Fire in which three adjacent, intensely burned headwater streams were monitored for postfire shade, summer streamflow, and maximum water temperature. These streams are in timbered lands where drastic changes in the structure of the forest canopy can affect water quality, especially temperature.

Water temperature is a determining factor in the composition and productivity of streams in the Klamath Mountains of southern Oregon and northern California. The temperature of valuable fish-bearing streams can be influenced by reducing forest canopy of riparian vegetation along headwater streams (Brown and others, 1971). Fish are greatly affected directly and indirectly by changes in water temperature. Cold water game fish, an important resource in the Klamath Region, are negatively affected as temperatures increase. Increased temperatures favor the introduction and proliferation of "warm water" species to the detriment of "cold water" species. Water temperature increases also indirectly affect fish through alteration of the stream environment, by increasing the abundance of fish pathogens and algae and by decreasing amounts of dissolved oxygen and aquatic organisms. Many stream temperatures in the area are already at critical levels for cold water game fish. The importance of water temperature as an indicator of water quality has not escaped the attention of land managers and is reflected in its inclusion in State and Federal water quality standards.

Changes in water temperature depend largely upon how much heat is received and the volume of water to be heated (Patton 1973). Heat can be lost or gained by a variety of mechanisms including evaporation, condensation, conduction, and convection. These factors, however, influence stream temperature very little compared to direct solar radiation (Brown 1969). The maintenance of water temperature largely becomes a consequence of the quantity and quality of shade-producing vegetation. Numerous studies have evaluated the effect of loss of shade-producing vegetation upon water temperature. Most of the studies have investigated the effects of forest harvest (Levno and Rothacher 1967, 1969, Brown and Krygier 1970, Meehan 1970, Holtby and Newcombe 1982); far less is known about the effects of wildfire (Helvey 1972). Intense wildfire, by destroying live riparian canopies, can greatly influence the amount of direct solar radiation reaching stream surfaces. Small, headwater streams may be most greatly affected because of low summer streamflows and large surface areas in relation to volumes. Shade from topography and dead riparian vegetation, where abundant, may play critical roles in minimizing temperature increases.

The objective of this study was to determine (1) type and abundance of shade in intensely burned headwater streams, (2) water temperature increases in streams flowing through an intensely burned area, and (3) the relationship

[1] Presented at the Symposium on Fire and Watershed Management, October 26-28, 1988, Sacramento, California.

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of streamflow to water temperature increase.

METHODS

The study was conducted on Bald Mountain within the Silver Fire Complex area on three headwater streams of approximately the same size within .8 km of one another. The three streams drain an area of approximately 420 ha located 40 km west of Grants Pass, Oregon, on the Siskiyou National Forest's Galice Ranger District. Stream orientations are generally northeast. Prefire overstory vegetation was dominated by mature Douglas-fir with understory hardwoods.

The area is characterized by rugged steeply dissected terrain and moderately-deep skeletal soils. Soils are similar in all three basins --well drained loams with clay loam subsoils underlain by graywacke sandstone parent material at a depth of 60 to 100 cm. Summers are hot and dry. Most of the precipitation occurs in the mild wet season from November to April.

In September 1987 the Silver Fire swept through the study area. In October 1987 a photo inventory was completed to determine high, moderate, and low intensity burn areas. The three stream basins in the study were classified as high-intensity burns, characterized by complete consumption of crowns of existing vegetation. Field reconnaissance indicated that the majority of the riparian zones burned with high burn intensity; however, there are riparian zones borderinq all three streams that exhibit some burns of moderate and low fire intensity. In moderate intensity burn areas crowns were partially consumed and in low intensity burn areas crowns remain largely intact.

Transects were established and marked for facilitating solar pathfinder measurements. Specifically, half-inch steel rebar was hammered 1 m into left and right banks of each stream. Each pathfinder measurement is 6m apart. There are five transects per cluster and four clusters per stream. Each cluster measures a stream segment 30m long. Site locations for clusters were chosen using a random grid.

A solar pathfinder was used to determine effective streamside shade for the maximum temperature period (Amaranthus 1983). The solar pathfinder consists of a spherical dome that reflects a panorama of the site including shade casting objects. Topographic and dead and live vegetational shade were quantified by viewing the sun's path diagram through the dome and summing shaded radiation values (percent of the days' total potential solar radiation) for each half-hour period for the sun's path on August 1, generally when maximum water temperatures are reached. Topographic, dead and live vegetational shade was individually tallied by differentially examining each shade-producing object as reflected through the spherical dome.

The solar pathfinder was set up between each transect in or as close to the center of the stream as possible. An azimuth and a linear measurement were taken from a bench mark (rebar at transect) and recorded. One technician made all the measurements on all three streams.

Streamflow measurements were made in all three streams on July 25, 1988 using a small flume, which was calibrated by the U.S. Geological Survey. One streamflow measurement was taken per stream. Stream temperatures were taken using calibrated minimum/maximum thermometers installed inside a protective rubber sheath and held in by 1/8-inch cable. The thermometers were installed at the top and bottom of each stream-monitoring area and recorded the maximum water temperature during the period from June 15 to September 15.

Data were subjected to analysis of variance. Means and standard errors were calculated for topographic, dead, live, and total shade. Tukey's multiple range test was used to compare differences ($p \leq 0.05$) among means between streams. Maximum water temperatures, summer streamflow, and total shade values were subjected to simple linear regression and analysis of variance.

RESULTS AND DISCUSSION

As expected, maximum water temperature was increased through intensely burned sections of streams. Increase was largest in Stream C where temperature increased 10.0°C (table 1). Stream B increased 6.2°C and Stream A increased 3.3°C. Stream A had significantly more shade from topography and live vegetation than Stream B and C (table 2). These two factors contributed to Stream A containing significantly more total shade. Streams B and C did not significantly differ in amounts of topographic, dead, live, or total shade. Dead shade provided the most shade averaged for all streams. Shade from dead vegetation was more than three times greater than topographic and two times greater than live vegetation (table 2).

Table 1--Maximum water temperatures above and below monitored area, stream length and summer streamflow.

Stream	Max water temp°C		Stream lgth.	Streamflow
	Above	Below	(meters)	July 25 (ft^3/sec)
A	16.7	20.0	2350	.076
B	14.4	20.6	1950	.053
C	12.8	22.8	1500	.035

Table 2--Percent streamside shade from topography and dead and live vegetation for three intensely burned headwater streams in southwest Oregon.*

	Percent streamside shade (standard error)			
Stream	Topography	Dead veg	Live veg	Total
A	7.6a(0.79)	10.8a(1.69)	16.4a(1.11)	34.4a(1.07)
B	4.2b(0.61)	20.8a(.51)	2.3b(1.31)	27.3b(.69)
C	3.8b(1.08)	19.6a(3.08)	3.4b(2.13)	26.0b(2.18)
All Streams	5.2(0.68)	17.0 (1.72)	7.4 (2.10)	29.6 (1.46)

*Columns not sharing the same letter are significantly different, p≤0.05.

Prefire monitoring in this area indicates that headwater streams generally average greater than 90 percent total streamside shade (Amaranthus, unpublished data). Average postfire total shade was nearly 30 percent for intensely burned streams. This represents a considerable loss of shade compared to prefire levels. Dramatic increases in direct solar radiation resulted in large but variable increases in water temperature. Water temperature increases were similar to those from other studies in Oregon investigating the effects of clearcutting on water temperature (Brown and Krygier 1967, Levno and Rothacher 1967). However, in the clearcutting experiments temperature increased more dramatically over a shorter stream reach. Unlike clearcutting, wildfire results in standing dead vegetation and where it is abundant it may help minimize temperature increases. In this study 57 percent of the postfire shade was provided by dead vegetation. Removal of dead vegetation shade from riparian zones by timber salvage or other postfire activities should be carefully considered where water temperatures reach critical levels for fish.

Variability in maximum water temperatures for the three stream strongly correlates with summer streamflow (r^2 =0.98, fig. 1). Maximum water temperature increase was inversely proportional to summer streamflow. Stream A had the highest streamflow and thus the greatest volume of water to be heated. Stream C had the least streamflow and thus the least volume of water to be heated. Water in Stream A, compared to Stream C, would travel more rapidly through the intensely burned section of stream, thereby decreasing time of exposure to direct solar radiation. Stream B would have intermediate characteristics between Streams A and C. These factors appear to influence maximum water temperature increase in headwater streams.

Considerable loss of live vegetation and large, but variable increases in maximum water temperature can accompany high intensity wildfire in headwater streams. However, review of the Silver Fire Complex Area indicates that less than 5 percent of the headwater streams burned in this manner and that postfire maximum water temperatures have not appreciably increased at the mouth of large downstream tributaries draining the fire area (P.A. Carroll, unpublished data)[3]. Numerous factors can account for this. Some authors have noted water temperatures decrease as streams passed through shaded areas downstream from open areas (Hall and Lantz 1969, Levno and Rothacher 1969). There may be some recovery of stream temperature in shaded areas downstream from high-intensity burn areas, although previous measurements of temperature recovery downstream from harvest areas (Amaranthus, unpublished data) and other studies (Brown and others 1971, Brazier and Brown 1973) have not demonstrated this cooling effect. Inputs of cooler ground water, increased summer streamflow following wildfire, and mixing cooler water from unburned tributaries would help minimize water temperature increases downstream. The amount of cooling would be largely dependent upon the magnitude of groundwater inputs, increase in streamflow and cooler water from unburned streams.

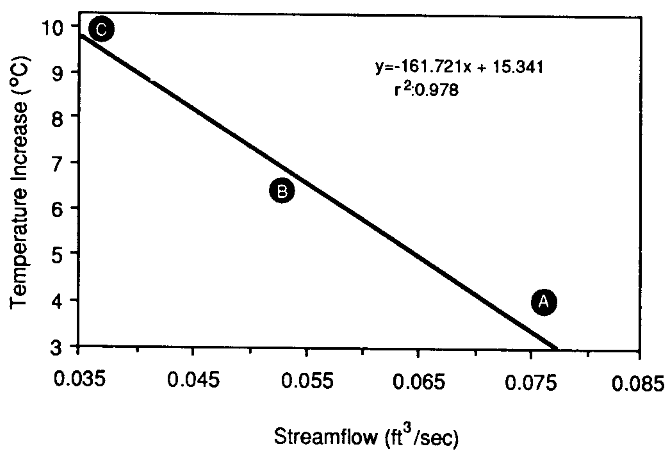

Fig. 1--Relationship of summer streamflow (X) to maximum water temperature increase (Y) for three intensely burned headwater streams (A, B, and C).

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Variability in maximum water temperatures for the three streams also correlates with total postfire shade (r^2=0.80, fig. 2). Stream A had the greatest total postfire shade and thus the least direct radiation reaching the water surface. It is unlikely, however, that the 8 percent increase in shade between Stream A and C could alone explain the 6.7°C decrease in maximum water temperature increase. Other factors could be influencing changes in water temperature between the streams such as the width-to-depth ratio of the channel. This could greatly affect the surface area and length of time water is exposed to radiation.

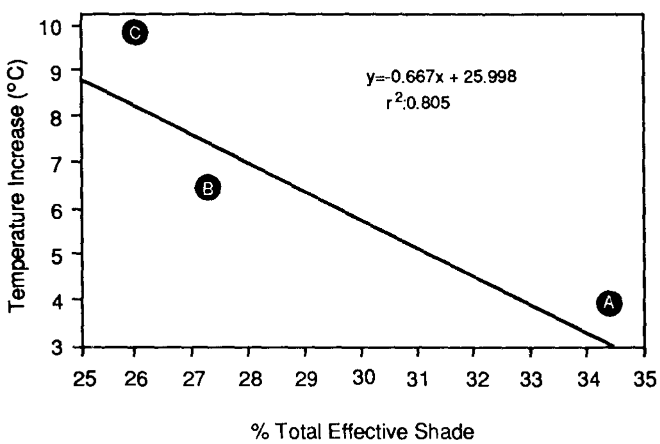

Fig. 2--Relationship of total shade (X) to maximum water temperature increase (Y) for three intensely burned headwater streams (A, B, and C).

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Effects of Fire Retardant on Water Quality[1]

Logan A. Norris and Warren L. Webb[2]

Abstract: Ammonium-based fire retardants are important in managing wildfires, but their use can adversely affect water quality. Their entry, fate, and impact were studied in five forest streams. Initial retardant concentrations in water approached levels which could damage fish, but no distressed fish were found. Concentrations decreased sharply with time after application and distance downstream, and there was no long-term entry. The numbers and kinds of stream insects were not affected. Simulations of retardant dispersal in streams showed fish mortality might occur from zero to more than 10,000 m below the point of chemical entry, depending on application parameters and stream characteristics. Guidelines to minimize adverse impacts from the use of fire retardants are suggested.

Chemical fire retardants play an important role in protecting forest resources from destructive fires. Their use has increased steadily since their introduction in the 1930's. Lowden (1962) reported that aerially applied fire retardant use in the U.S. increased from 87,000 liters in 1956 to more than 28 million liters in 1961. During 1970, 64 million liters of fire retardant were applied aerially to forest and rangeland fires (George 1971). USDA Forest Service aerially applied 55 million liters of fire retardant in 1977. More than 71 percent of this use was in California, Oregon, and Washington (Norris and others 1978).

Fire retardants have changed since their first introduction. Borate salts, the first retardants, were effective and long-lasting, but were also phytotoxic and soil-sterilants, and are no longer used (Fenton 1959). Bentonite clay in water is not as long-lasting or as effective as alternative materials (Phillips and Miller 1959). Ammonium phosphate, an effective fire retardant marketed in several formulations, is relatively long lasting, nontoxic and easy to apply (Douglas 1974). The ammonium-based fire retardants as a group account for nearly all chemical retardants used in controlling forest and range fires today.

The possible adverse effects of chemical fire retardants on the environment have received relatively little attention, probably because of the importance of these chemicals in fire control and their seemingly innocuous nature. However, even materials of inherent low toxicity can cause adverse environmental effects when organisms are exposed to toxic amounts. Research and development efforts have concentrated primarily on developing effective fire retardants, delivery systems, and strategies for use.

As the intensity of fire retardant use increased, incidents of misapplication or adverse environmental effects have begun to appear. There have been several reports of fish kills when retardants were applied directly into streams, but documentation is marginal. Fire retardants are alleged to have killed a number of trout in one stream in California, but the stream soon returned to normal. In 1969, a large number of juvenile salmonids and more than 700 adult salmon were killed in an Alaskan stream. While retardants were used near the river, the specific cause of death of the fish was not determined. Adult salmon entering the river 4 days later exhibited no toxic reaction (Hakala and others 1971).

As a result of these incidents, and concerns among resource managers that fire retardants may adversely affect the environment, an ad hoc interagency study committee was formed in 1970 (Borovicka 1974). The objective of the committee was to foster and coordinate research needed to evaluate the environmental safety of chemical fire retardants (primarily their effect on water quality and aquatic organisms). Toxicology research conducted by Fish and Wildlife Service, Bureau of Land Management, and National Marine Fisheries Service established dose-response relationships for use in evaluating the effects on fish of specific levels of fire retardants in streams (Blahm and others 1972; Blahm and Snyder 1973; Borovicka and Blahm 1974; Johnson and Sanders 1977). Forest Service scientists at the Northern Forest Fire Laboratory (Missoula, Mont.) conducted an initial simulation study of retardant distribution in streams (Van Meter and Hardy 1975).

The Pacific Northwest Forest and Range Experiment Station studied the behavior of retardant materials in streams, determined their effect on selected aquatic species in their natural habitat and (through simulation) estimated the effects of retardant application on fish mortality in streams of different characters. This paper draws heavily on the

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[1]Presented at the Symposium on Fire and Watershed Management, October 26-28, 1988, Sacramento, California. This is paper 2476 of the Forest Research Laboratory, Oregon State University, Corvallis.

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PNW research effort (Norris and others 1978), and suggests planning for resource managers concerned about minimizing fire retardant impacts on streams.

METHODS FOR FIELD STUDY

We applied an ammonia-based fire retardant to five streams in Oregon, Idaho, and California (Norris and others 1978). The application crossed a segment of four of the streams and was parallel (to within 3 m) on the fifth (table 1, fig. 1). The pattern of ground level application we used in the field studies (fig. 1B) is a simplified version of the pattern of retardant deposition resulting from operational aerial application (fig. 1A). Stream water samples collected periodically for up to 13 months after application at locations up to 2700 m downstream were analyzed for various forms of nitrogen and phosphorus. Samples of benthos and insect drift were also collected and evaluated for shifts in species diversity and abundance.

RESULTS OF FIELD STUDIES

Effects of Retardant on Stream Water Chemistry

The principal chemical species in the stream the first 24 hours after application were ammonia nitrogen (NH_3 + NH^+_4) and total phosphorus. Un-ionized ammonia (NH_3) is of primary importance because of its potential toxic effects on aquatic species. The amount of NH_3 relative to NH^+_4 is dependent primarily on pH (Trussel 1972). As the pH increases, the proportion of ammonia nitrogen present as NH_3 increases. The phosphorus may be important in downstream eutrophication. After 24 hours, nitrate (No^-_3) and soluble organic nitrogen are the primary retardant components in the stream. These are transformation products of the diammonium phosphate in the retardant mixture. Both nitrate and soluble organic nitrogen are low in toxicity and are natural components of aquatic ecosystems. Because NH_3 is most important, the results in table 2 and figure 2 emphasize ammonia nitrogen (NH_3 and NH^+_4) or un-ionized ammonia (NH_3).

Table 1--General characteristics of the study locations and streams

Stream and Location	Climate	Soil and parent material	Vegetation	Stream characteristics[1] Width	Depth	Discharge
				(m)	(m)	(l/s)
Tohetie Oregon: representing Coast Ranges	High rainfall--cool, moist summers, winter snow rare	Inceptisol Andic Haplumbrept Siltstone and claystone	Douglas-fir, Sitka spruce Western Hemlock, Alder Salmonberry	5.4	0.03	2.3
Lewis Same	Same	Same	Same	2.8	0.20	13.7
Quartz Oregon: representing Cascade Range	Moderately high rainfall--warm, dry summers, occas. winter snows	Inceptisol Dystric Cryochrept Red breccia and basalt	Douglas-fir, Alder	2.4	0.18	35.4
Bannock Idaho: representing Intermountain Region	Warm, dry summers, winter snowpack	Mollisol Typic Cryoboroll Quartz monzonite (acid igneous)	Ponderosa pine	1.0	0.29	6.0
San Dimas Southern Calif.: representing areas of heavy chaparral	Hot, dry summers warm, moderately dry winters	Alfisol Mollic Haploxeralf Metamorphic and acid igneous	Chaparral	1.2	0.18	7.1

[1]Late summer, at time of application of fire retardant. All retardant applications crossed the stream (see fig. 1), except Tohetie Creek where the long axis of the application was parallel to the stream, with the edge of the distribution pattern 3 m or more from the edge of the stream.

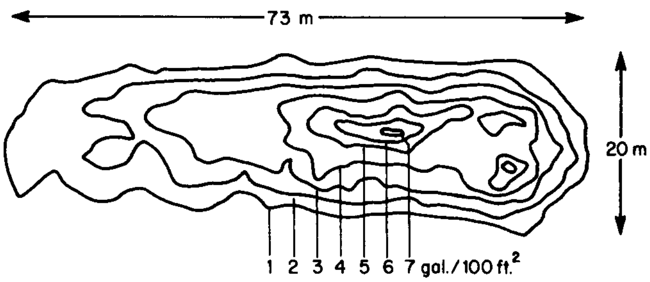
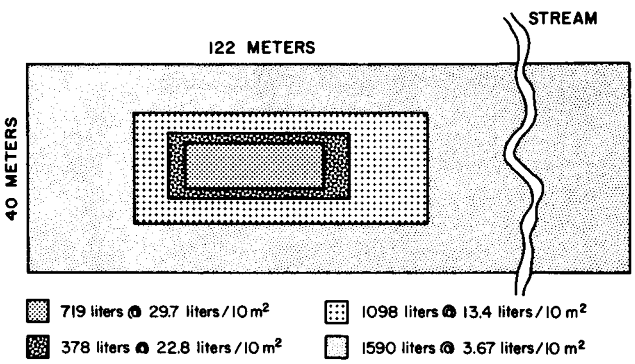


Figure 1--Retardant application patterns.
A, Typical retardant application used in developing a pattern for the test applications (X 4.07 = liters/10 m²).



B, Pattern of retardant application (applied with hoses at ground level) for cross-stream treatment at Lewis, Quartz, and Bannock Creek study sites. The same application pattern was used for Tohetie Creek except the long axis of the application was parallel to the stream and the edge was not closer than 3 m to the stream. A slightly modified pattern, applied by helicopter was used at San Dimas (Norris and others 1978).

Direct application of retardant to the stream surface produced the highest concentration near the point of application. Concentration decreased both with time after peak concentration and distance downstream (fig. 2, table 2). Detectable changes in stream water chemistry were noted up to 2700 m downstream. The changes we measured were of short duration and not important either toxicologically or with respect to eutrophication downstream. In our test, however, regulations required a low rate of application (maximum planned concentration 0.5 ppm NH_3), and only a single application was made on each stream. The effect of rate of application, vegetation density in the streamside zone, and other factors on retardant levels in streams are discussed in the section on results of simulation studies.

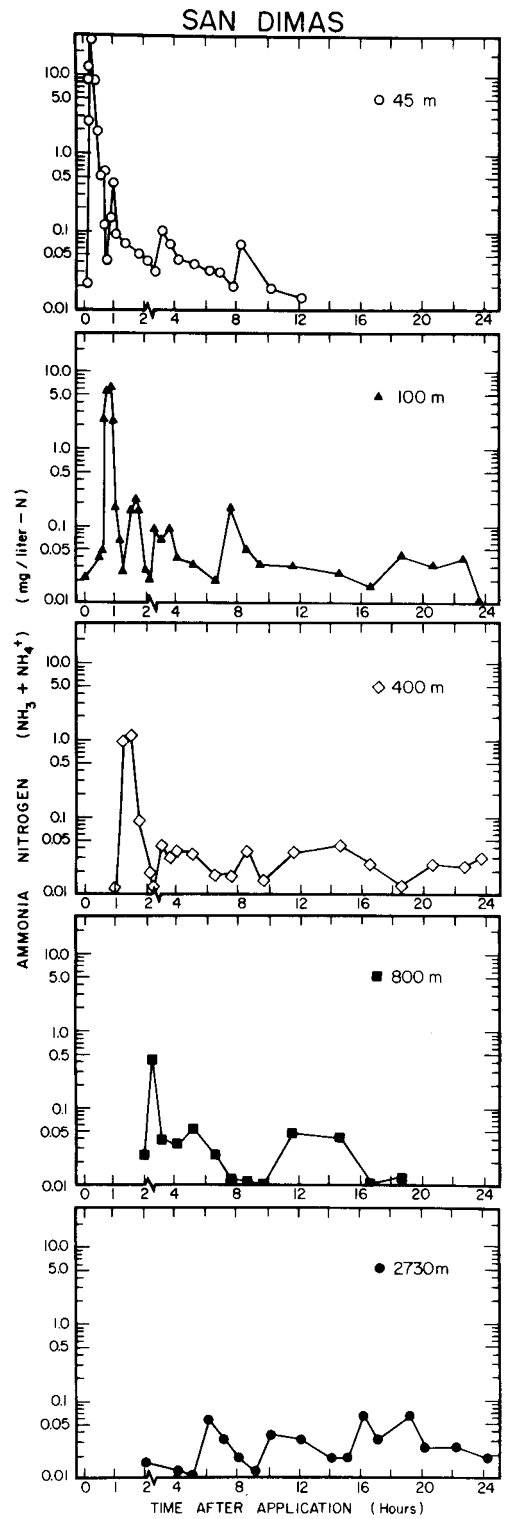


Figure 2--Concentration of ammonia nitrogen (NH_3 + NH_4^+) at various times after application and at five distances downstream from the application zone for East Fork San Dimas Canyon. The last samples were collected at 45 m and 800 m at 12 h and 18.5 h after the application.

Table 2--Effect of time and movement downstream on maximum concentrations (max. cone.) of ammonia nitrogen (NH_3 + NH^+_4) from retardant application zone (r.a. zone)

Study site[1]	Max. cone. NH_3 + NH^+_4 45 m downstream from r.a. zone	Max. cone. NH_3 45 m downstream from r.a. zone[2]	Time for indicated dilution, 45 m downstream from r.a zone		Max. cone. at various distances below r.a. zone as percent of max. cone. at 45 m		
			10-fold	100-fold	200 m	400 m	800 m
	ppm-N	ppm-N	minutes		percent		
Lewis Creek	3.34	0.02	18	60	29	8	3
Quartz Creek	15.81	0.15	23	90	4	5	3
Bannock Creek	13.56	0.03	24	225	8	2	1
San Dimas Canyon	29.95	0.32	10	25	19	4	1

[1]Retardant applied directly to stream surface.

[2]Calculated from free ammonia concentration (Trussel 1972).

Direct application to the stream surface was the primary source of retardant components in the streams. Once initial residues cleared the stream system, only minor residues of retardant entered the streams from the streamside zone.

Relatively narrow untreated strips in the riparian zone are probably sufficient to largely eliminate movement of retardant from the land to the stream. Where the long axis of the application zone was parallel to the stream (Tohetie Creek, where the edge of the treated area was only 3 meters from the stream), we found no evidence of significant elevation of concentration of retardant components in the stream, even after periods of heavy precipitation.

Effects of Retardant on Stream Organisms

The experimental retardant application made in this study did not kill or incapacitate fish in the first 24 hours, or the density or diversity of stream drift or the stream benthic community in the first year after application (Norris and others 1978). This does not mean retardant application will not affect these organisms, only that they were not affected to a detectable degree by the rates of application used in these applications. The effects of higher rates of application on fish are dealt with in the section on simulation.

The high degree of natural variability in the biological communities in these streams (over both time and distance) is an important factor in masking small or temporary changes in community structure. This means fire or fire control-induced changes in stream community structure must be large to be detected without intensive sampling. Retardants which enter streams (even in high concentrations) are not expected to permanently alter community structure. As water quality returns to normal, repopulation is expected and community structure should shift towards pretreatment status.

METHODS FOR SIMULATIONS

Estimations of fish mortality following direct injection of retardant was obtained with a four-component model. First, a model of retardant dilution in streams was derived from dye dilution experiments in the field. This model was combined with another representing retardant application rates obtained from actual drop patterns(George and Blakely 1973), and a model predicting retardant interception by vegetation along the riparian zone (Anderson 1974). These three components, which predicted retardant concentrations in a variety of streams representing a wide range of mixing parameters, were linked to a model structured with fish mortality data taken from Blahm and Snyder (1973). Details of the model are in Norris and others (1978).

RESULTS OF SIMULATIONS

Simulations using the model had the objectives of (1) developing methods for predicting the concentration of retardant in streams when direct applications to the stream surface occur, (2) developing methods for describing the dispersal of retardant in streams, both with time after application and distance from the application, and (3) integrating these two techniques with data on toxicity to fish to evaluate the effects of retardant applications in various types of streams on fish mortality. The term "mortality zone" means the stream reach where fish mortality (0 to 100 percent) occurs. The mortality zone shifts downstream with time as the toxicant is carried with the stream water.

The simulation studies show that

- Direct application of retardant to many streams is likely to cause fish mortality.

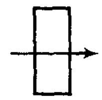
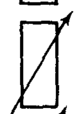
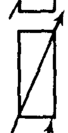
- The magnitude of the mortality and the distance over which it occurs varies with three elements: (1) the characteristics of the application, (2) the characteristics of the zone of application, and (3) the characteristics of the streamflow.

    1. The characteristics of the application include orientation of the line of flight to the stream, size of load dropped, number of loads dropped, and the timing and placement of subsequent loads relative to the first load. For instance, a retardant application across and perpendicular to a stream produces a much smaller mortality zone than an application whose long axis is centered on the stream. If the rate of application is doubled (8000 instead of 4000 liters released over the same area) the mortality zone increases by a factor of 10 or more. We did not simulate the effects of multiple loads or the timing and placement of subsequent loads on the mortality zone, but believe the effects of additional loads will be at least additive to the effects of the first load. The characteristics of the application can be controlled by the fire control officer and the applicator to minimize the mortality zone (table 3).

    2. The characteristics of the site. Several characteristics of the application site determine the initial concentration of retardant in the stream and the length of the fish mortality zone. Narrow, deep streams have a much lower initial concentration (therefore a shorter mortality zone) than shallow, wide streams (assumes equivalent flow properties; fig. 3). The more dense the vegetation canopy, the less chemical that falls directly on the stream and the shorter the mortality zone (fig. 4). These site characteristics can be recognized and retardant applications adjusted accordingly to minimize the size of the mortality zone.

    3. Characteristics of streamflow. Streamflow characteristics influence the length of the mortality zone by determining the degree and speed of mixing and dilution of retardant with downstream travel. Simulation results show streams with a smooth channel have a longer mortality zone than those with many pools and riffles (assumes equal streambed gradient). Pools and riffles cause the peak of retardant concentration to spread out, thus reducing the magnitude of exposure. Increasing stream discharge with distance

Table 3--Fish mortality related to orientation of stream through retardant application zone, and to amount of retardant dropped (simulation results)

Application zone and stream direction	Angle between long axis zone and stream[1]	Distance over which 100 pct mortality occurs	
		Standard drop	Standard drop times two
	degrees	-------- meters --------	
	90	50	480
	67.5	50	560
	45.0	100	1000
	22.5	240	>1000
	0	1000	>1000

[1]At 90°, the long axis of the retardant application zone is at a right angle to the stream. The stream passes through the point of maximum retardant deposition in the retardant application zone.

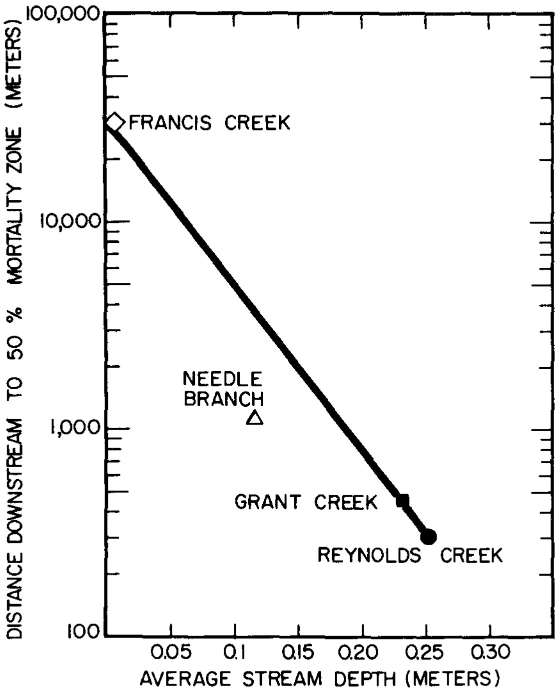


Figure 3--Effect of average stream depth on simulated length of fish mortality zone. See table 4 for stream characteristics.

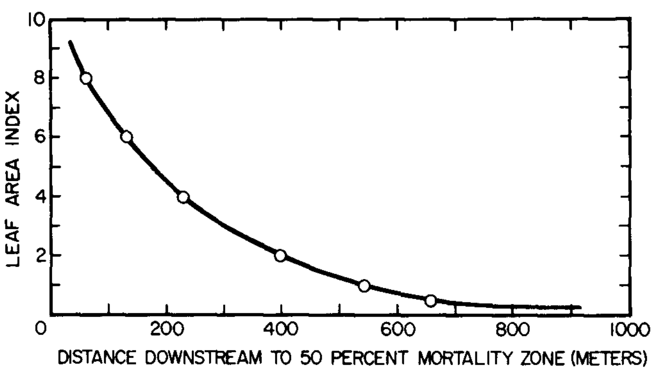


Figure 4--Length of simulated 50 percent fish-mortality zone as affected by density of streamside vegetation which intercepts retardant.

downstream (because of the inflow of groundwater and contribution from side streams) is also important as it increases dilution of the retardant. These characteristics of streamflow can be recognized by the manager.

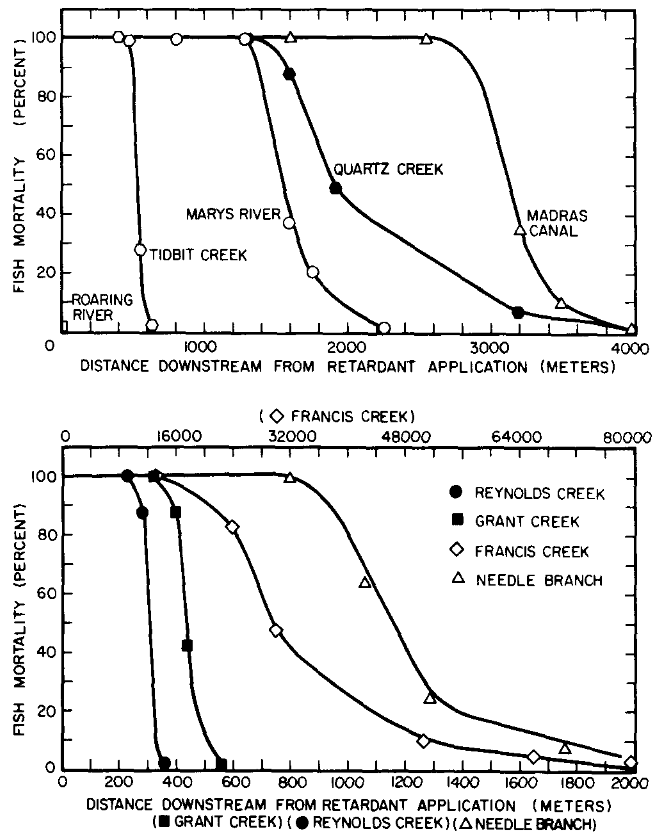


Figure 5--Simulated fish mortality at various distances downstream in several streams. Streams are oriented parallel with and through long axis of retardant application and have leaf area index of 1.0. See table 4 for listing of individual stream properties.

The results of simulation in a series of streams help illustrate the concepts (fig. 5, table 4).

PLANNING TO PROTECT STREAMS

Relatively large fires (more than 400 h) burning major portions of the watershed of perennial streams may have substantial effects on stream water quality and stream biological communities. Fire control practices such as bulldozing or hand clearing fire lines or the use of chemical fire retardants, can also impact streams. Fire control officers must use these techniques singly or in combination to achieve the appropriate balance between damage to the stream caused by fire and damage to the stream caused by fire control practices.

Our research indicates that applications of retardant that fall outside the riparian zone should have little or no effect on stream water quality. Fire control officers can plan on use of retardants away from the riparian zone with

Table 4--Description of mountain streams used in simulations

Stream	Stream characteristics	Width	Depth	Velocity[1]
		(m)	(m)	(m/hr)
Quartz Creek	Riffles and pools	4.23	0.19	206.9
Roaring River	Extremely fast and turbulent; no pools	9.45	0.49	4621.1
Marys River	Slow and channelled	5.79	0.31	388.8
Tidbits Creek	Riffles and pools	4.57	0.41	817.5
Madras Canal[2]	Rapid and channelled	1.5	0.17	1425.0
Reynolds Creek	Slow and channelled	2.23	0.25	450.9
Grant Creek	Slow and channelled	1.49	0.23	326.9
Needle Branch Creek	Riffles and pools	0.73	0.11	101.8
Francis Creek	Riffles and pools	0.94	0.04	258.9

[1]Velocity determined from dye dilution experiments. Mixing parameters are described in Norris and others (1978).

[2]An irrigation canal.

assurance that stream quality will not be significantly impaired.

When planning fire control with retardants near streams, attention needs to be given first to applications which may fall directly on the stream surface, and second to applications which fall in the riparian zone. Direct application to the stream surface is most likely to cause fish mortality. Applications in the riparian zone may affect water quality, but not to the point of causing major toxic effects. Potential impacts on downstream eutrophication need to be considered, however.

The key to successful applications (those that achieve fire control objectives and protect stream water quality) in each case is adequate planning before fire occurs (Borovicka 1974; Borovicka and Blahm 1974), including (a) identification of stream sections which need to be protected, and (b) development of retardant application plans to minimize adverse effects on the stream.

Identifying Streams for Protection

It may not be possible to do advance planning for protection of all streams. Therefore, it is necessary to identify streams that are of greater importance and are more likely to be affected by fire. Streams in high fire risk areas, for instance, should receive attention before those where the risk of fire is lower. Streams needing attention first include those which provide water for fish hatcheries, domestic use, or other special purposes. Streams that are particularly important for recreational use or fish production, or are habitat for rare or endangered species also need attention.

All parts of the stream system cannot be included in prefire planning. First order streams may be too small for effective protection. Streams in steep canyons where mechanical fire control is not possible, and where retardant must be dropped from higher than normal elevation, may also have to be excluded, at least from the first efforts to develop plans to permit retardant use while protecting streams.

Development of Applications Plans

Development of application plans must consider all the three elements important in determining the length of the zone of mortality discussed above. These are the characteristics of the site, the characteristics of streamflow, and the nature of the application. The most important site characteristics are the width and depth of the stream, and the leaf area index over the stream. The most important characteristics of streamflow are the ratio of pools and riffles, stream velocity, and degree of channelization.

These characteristics can be used in connection with the findings of the simulation studies to obtain an estimate of the initial level of retardant deposition to the stream--the level that will produce an acceptable mortality zone. Clearly, there are levels of deposition which will cause no mortality. When this level of protection is required, it can be achieved with good planning and careful execution. In those instances where a lower level of protection is adequate, this can also be achieved.

When an acceptable level of retardant deposition has been determined, the third element (the nature of the application) is considered. The procedures for estimating deposition developed in the simulation studies can be used to determine the size of load and orientation to the stream that will not cause a rate of deposition in excess of that determined to be acceptable. This information should then be cataloged and stored so it can be quickly retrieved when fire control operation commences in or near subject areas.

CONCLUSION

These methods require substantial subjective judgments on the part of the resource manager. However, they provide the logic and a process by which managers can plan fire control operations with retardants. Information presented in the report by Norris and others (1978) can be used to evaluate the impacts of retardant use on water quality as opposed to the impact of fire on stream chemistry or the impact of other methods of control. The development of GIS (geographic information systems) capabilities, the ready availability of aerial photos, and the expanding use of computers by managers make the type of prefire planning described above quite achievable. Further research and documentation of experience in the field are necessary to permit improvement of these preliminary guidelines and to help insure that the use of chemical fire retardants does not produce unexpected impacts on the aquatic ecosystem.

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Maximizing Vegetation Response on Management Burns by Identifying Fire Regimes[1]

V. Thomas Parker[2]

Abstract: Maintenance of vegetation is a central goal of watershed management. When prescribed burning of chaparral is included in management practice, then it is important for managers to understand and use the natural chaparral fire regime to maximize vegetation response. Variations from the natural fire regime in intensity, frequency, season, and environmental conditions at the time of burning can all have substantial effects. These factors interact differently with the species that comprise chaparral. This paper focusses on the variation in responses of different groups of chaparral species to changes in fire regime.

Prescribed burning often has been used to reduce fuel loads to meet fire safety objectives. An assumption inherent in this type of management is that prescribed burning reduces the likelihood of a wildfire yet has little net effect on the vegetation, which is basically true for many species and communities. One exception, however, is California chaparral, widely recognized as a fire-type vegetation. Chaparral tolerates burning only under certain conditions at limited times of the year. Under other conditions or times, the recovery of chaparral following prescribed burning can be limited. Particular types of species are most sensitive and several environmental conditions appear to exert the most influence on recovery. My objective in this paper is to illustrate these vegetation and environmental characteristics. Only after a careful consideration of these factors can managers hope to maximize the response of their vegetation.

Overall watershed management involves not only short-term objectives like fuel reduction, but also, the long-term objective of maintaining the health of the vegetation. The health of the vegetation depends upon species diversity as well as ensuring vegetation recovery. Many chaparral dominants in the genera _Arctostaphylos_ and _Ceanothus_, for example, are usually killed in fires and are greatly reduced in regeneration following most prescribed burns (Parker 1987b). Twenty species of these two genera, furthermore, are listed rare and endangered species or under consideration. Chaparral contains a number of additional sensitive species. Most of these rare and endangered chaparral species are vulnerable to management practices like prescribed burning. Protection of rare and endangered species is an issue that will continue to increase in importance.

INFLUENCES ON RECOVERY OF CHAPARRAL

Vegetation Characteristics

The diversity of species in chaparral is reflected in the variation in plant response to burning. This diversity can be grouped according to population changes and methods of surviving fire. In this way, four regeneration syndromes can be distinguished. Many chaparral dominant species, for example, are obligate seeders with respect to fire. This means that their populations are killed by fire and require regeneration from dormant seed stored in the soil seed banks. Other dominant species also have soil seed banks, but can also resprout and are termed facultative sprouters. Populations of another group of woody species are called obligate sprouters; they resprout after fire and have no soil seed reserves. A fourth important group of species are post-fire annuals and short-lived perennials that are present only as dormant soil seed banks before a fire. Several recent reviews of these regeneration syndromes exist and should be consulted for more information (Christensen 1985, Keeley and Keeley 1988, Parker and Kelly, in press).

What is apparent is a spectrum of species, some of which sprout and some of which maintain seed banks in the soil. The various combinations establish a spectrum of vulnerability for management practice. Some species are extremely resilient, while others are readily eliminated. To maximize the diversity and rate of vegetation response and to know how careful one must be requires knowledge of what combination of species exists at the site, at least in terms of their regeneration responses.

The rate of chaparral post-fire recovery and the resilience of the vegetation depend in part, therefore, on the combination of species present at a site. If all the woody species are obligate sprouters and a large and diverse seed bank of temporary species exists, then the site will appear to recover rather rapidly. If all the woody species are obligate seeders and few temporary species are in the seed bank, then the

[1]Presented at the Symposium on Fire and Watershed Management, October 26-28, 1988, Sacramento, California.

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vegetation remains open and appears to recover rather slowly.

Environmental Variables

Not only are vegetation characteristics important to understand, but so too are environmental characteristics. For example, in Marin County, California, serpentine soil and sandstone soil chaparral occur side by side in many areas, but these two chaparral vegetations respond very differently to fire at any given season or condition. In part the response reflects species differences, but the species in common also respond uniquely, indicating that different phenologies result from soil-influenced moisture and nutrition environments (Parker 1987b). The result is that timing for a prescribed burn that would be effective in one stand would be disastrous in the other.

While soil type is a demonstrably important influence, so too are other environmental conditions. A large proportion of chaparral plant species depend upon soil seed banks for regeneration (Parker and Kelly, in press). To survive the high soil temperatures during fires, many seeds must be dry, while other seeds require relatively high temperatures to break open their seed coats so that germination is stimulated. Soil moisture conditions vary greatly in prescribed burns and will influence survival of certain species whose seed imbibe water, while reducing germination rates of species whose seed are stimulated by higher temperatures. These types of variation in influence on recovery, and their interaction with other vegetation characteristics will be more fully described with reference to the concept of fire regime.

FIRE REGIME CONCEPT

In the first year or two following a fire, chaparral is a substantially different vegetation from that which was burned. Obligate seeders are present as populations of seedlings lacking a soil seed bank reserve, the facultative sprouters as surviving resprouts and seedlings, the obligate sprouters as surviving resprouts, and the temporary vegetation as reproducing annuals and short-lived perennials with seeds on or close to the soil surface. A second fire in the first several years of recovery has great impact on chaparral. Such a fire eliminates the obligate seeders, kills many of the resprouts, and reduces any seed populations on or near the soil surface (Zedler and others 1983). Species diversity is reduced, cover is reduced, and the vegetation opened up for invasion by species from adjacent habitats.

The effect of a second fire illustrates that chaparral vegetation is not adapted to fire *per se*, but is adapted to a particular fire regime. The phrase "fire-adapted" ignores the complexity of the fire regime to which chaparral has adapted. Fire regime is not a new concept, it has been more clearly defined recently, however, as including (1) the type of fire; (2) the intensity of the fire; (3) the season of the fire; and (4) the frequency of fires (Gill 1975, Gill and Groves 1981). When any of these characteristics are at variance with those to which the vegetation is adapted, then recovery may be poor. Two fires in a short period constitute too great a fire frequency for chaparral vegetation to tolerate.

CHAPARRAL FIRE REGIME AND RESPONSE OF THE VEGETATION TO PRESCRIBED BURNS

Chaparral vegetation has evolved in the context of high-intensity canopy fires that usually come in the late summer or fall every 30 to 100 years (Hanes 1977, Keeley and Keeley 1988). Prescribed burns vary in a number of characteristics from this type of fire regime. In the short term, as we have seen, species differ in their response to these variations. Populations of some species are immediately reduced while others show high survival. Species showing high rates of prescribed burn survival may decline in the long term.

One common difference between prescribed burns and natural fires is in the season of the burn. Many prescribed burns, especially in urban areas, may be conducted in winter or early spring for safety reasons. This can create several problems. A common dominant species, *Adenostoma fasciculatum*, or chemise, is particularly sensitive to season of burn. Mortality increases in burns from fall to winter to spring (Parker 1986, 1987a, Rogers and others, these Proceedings). This type of response has been known in chemise for several decades and has been used to convert chemise stands to other vegetations in the past (Biswell 1974). A problem for watersheds today, however, is that while chemise may be eliminated, controlling what replaces chemise could be more difficult. For example, invasive species like French or Scotch brooms are expanding and are often minor components of watersheds. Opening up of habitat by prescribed burns provides opportunity for these species to expand their own populations. In contrast to chemise, many resprouting species are less sensitive to season of burn.

Another problem with out-of-season burns is that as the burn occurs later in the winter and spring, fewer and fewer species germinate from dormant seed banks. The consequence is that reestablishment of native chaparral may be delayed into the second year, while a number of other potentially invasive species may establish. Less of the watershed has a cover for the remainder of the growing season and into the next year. The watershed becomes an erosion risk for a longer period of time. Availability of soil nutrients is increased for a short period of time after a fire, but, if germination is delayed, then opportunity to recover those nutrients is delayed and lost.

As already indicated, frequency of fires is also a great problem, especially if the watershed is being manipulated as a whole for fire safety purposes. When fire safety is the only consideration, maintaining chaparral as a young vegetation is an important consideration. Thus, on first thought, a relatively short fire-free interval would be the best policy for fire safety. But too short a fire-free interval may result in degeneration of the stand in the long run and create large-scale problems. Even an interval as long as 20 years could be too frequent. Species utilizing soil seed banks for regeneration need time for seed production, and time to incorporate sufficient seeds at a depth that can survive a fire. Movement of seeds down to the minimum soil depth required is a process that has not been studied, and probably occurs at different rates in different locations depending on slope, soil texture and structure, rainfall patterns, animal activity, and other factors. Not all individuals survive a fire, even among the most resilient sprouters. A 20-year fire frequency may also be too short for obligate sprouters, which effectively reproduce only in older stands. Such a regular interval may result in loss of their recruitment, and cause a loss in population size as individuals are lost in fires but not replaced. The net result is that while attempting to maintain fire safety, the vegetation loses species diversity, and surviving populations are reduced in density. An opened-up chaparral may allow invasion of species that are more flammable and may decrease fire safety in the long run.

Another consideration in planning a fire management program that includes prescribed burning of chaparral is that a diversity of fire-free intervals for any one site may work better than a regular interval. Recall that there really is a diversity of responses among the species that comprise chaparral. Any consistent fire frequency will favor one set of species over all others.

Previous research has also determined that prescribed burns conducted when soils contain moisture can seriously reduce the response of the seed bank (Kelly and Parker 1984, Parker 1987a, 1987b, Parker and Rogers 1988, Kelly and others, these Proceedings). There are two very different reasons for the reduction in seedling establishment. One is that many species which form persistent seed banks produce seeds that absorb water, but remain dormant unless they have been cued to germinate, usually in response to fire. When seeds have absorbed moisture, their ability to resist heat is greatly reduced (Sweeney 1956, Parker 1987b, Parker and Rogers 1988, Rogers and others, these proceedings). Even though fire intensity is reduced in a prescribed burn, the fatal temperature range for these seeds is reduced to as low as 70 C for less than 30 minutes. Such an intensity and duration in moist soils occurs to several cm in depth, beyond the depth of most seeds.

The second class of seed response is quite opposite to the one already described. In some types of seeds, the seed coat is thick and water is not absorbed, as in species of the Rhamnaceae, Leguminosae, and Convolulaceae. Therefore, moist soil during a burn is not fatal for these species (Parker 1987b). The problem is that the intensity and duration of heat is generally too low to stimulate germination. The consequence is a lack of seedling establishment in the first year, and those that germinate in following years are generally not able to compete with the established vegetation. This condition has been observed under field conditions with *Ceanothus greggii* in San Diego County. In stands burned in early winter, where *C. greggii* and *Adenostoma fasciculatum* had shared dominance, chemise now totally dominates (White 1988).

IMPORTANCE OF SPECIES DIVERSITY IN CHAPARRAL

The importance of careful management practices is especially clear with respect to species diversity in chaparral. Species that comprise chaparral vegetation have been shown to vary in their regeneration methods. It should come as no surprise that they also differ greatly in a number of other characteristics. Chaparral species flower, fruit, and grow throughout the year. This variation in phenology or timing of activity patterns means that species differ in how much moisture is contained in the aboveground portions of the plants. Those active later in the season maintain higher amounts of moisture in their foliage. Further, species differ in the size and shapes of leaves, in stem structure and diameter classes, indeed, in all the characteristics that influence flammability. Mixtures of species minimize the ignition potential of a stand by providing a mosaic of flammability.

Species diversity in chaparral means a diversity of tolerances and responses. Even when conditions cannot be controlled throughout a prescribed burn, overall, a dense and rapid recovery is still possible if a diversity of species is present. Diversity will maximize the total chaparral cover, and will prevent grasses, brooms, or other invasive species from penetrating chaparral and later acting as sources of flash fuel ignition.

Other issues related to diversity are well known. Species differ in their susceptibilities to a variety of environmental stresses. For example, a pathogenic fungus causes large areas of dieback in *Arctostaphylos myrtifolia* stands near Ione, California, at the present time (Wood and Parker 1988). Similar diebacks have been observed in other species of chaparral. Predicting such damage is difficult, because it may result from the combination of pathogen source and environmental stresses. The result is a vegetation that is less resistant to ignition, to invasion of other species, or other problems. Controlling these problems may not be possible, but maintaining a diverse stand of chaparral will reduce the impact of stress-induced dieback of a species on a watershed.

CONCLUSIONS

Whether to maintain water quality, to control erosion, or for other objectives, it is important that watershed managers maintain a healthy vegetation cover. When chaparral is one of the components, then particular care must be taken. Chaparral is sensitive to prescribed burns because fires kill a large number of individuals or at least their aboveground parts. Woody chaparral species are slower to regenerate and more susceptible to climatic variation than many other plants, and recovery time is increased. Chaparral should not be considered a fire-adapted vegetation, but rather one adapted to a particular fire regime. Variations from that fire regime can reduce the vegetation response by a variety of mechanisms, from increasing mortality to simply not stimulating germination. The greater the number of fire regime factors that vary from the desirable norm, the greater the impact on the vegetation. The examples provided examined fire season, fire frequency, fire intensity, and other conditions at the time of the fire.

Also important to these responses to a prescribed burn are the types of species. Regeneration characteristics vary among chaparral species. Their sensitivity to changes in season, frequency, and intensity also vary. The response of a particular watershed to a prescribed burn depends upon environmental conditions at the time of the burn and the combination of species present. This uniqueness of response underscores the need to know the species present and to understand the types of functional responses present in those species.

The phrases "fire-adapted" and "chaparral vegetation" hide considerable complexity. Other characteristics that are important sources of variation include soil texture and mineral composition, as in serpentine chaparral. In order to maximize vegetation response to management intervention practices such as prescribed burning, it is necessary that (1) the component species be understood in terms of their types of regeneration modes; (2) seasonal timing be as close to a natural timing (summer-fall) as possible; (3) fire-free intervals be relatively long and variable; and (4) other factors such as soil type and soil moisture at the time of burning be known and controlled.

ACKNOWLEDGEMENTS

I thank the Marin Municipal Water District, the Rare Plant Project and Region 2 Office of California Department of Fish and Game, and the Mann County Open Space District for support during studies mentioned in this paper. I also thank Vicky Kelly, Sam Hammer, Chris Rogers, Mike Wood, and Dan Kelly who helped in various aspects. This paper was greatly improved by the comments of Jason Greenlee and two reviewers of the Proceedings and I thank them for their patience.

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The Effects of Fire on Watersheds: A Summary[1]

Nicholas Dennis

Over the past three days we have been presented with the results of a most impressive quantity and quality of research on the effects of fire on watersheds. My attempt to summarize these papers will hardly do them justice, but hopefully will recapitulate some of their more important and generalizable findings. My comments are organized into the following categories: soil temperature, soil nutrients, soil erosion, soil hydrology and streamflow, vegetation structure, stream temperature, and impacts of firefighting.

SOIL TEMPERATURE

Alex Dimitrakopoulos reported the results of a laboratory investigation of the effects of soil heating on soil temperature and on the role of moisture. He and his colleagues found that, except for prolonged heating representative of intense wildfire, extreme soil temperatures are confined to the top 5 cm of soil. Short-duration heating, which approximates conditions characteristic of most prescribed fires, causes temperatures to reach lethal levels for living tissue only within the top 1 cm of soil.

Soil moisture strongly influences the effects of soil heating. Wet soil conducts heat relatively rapidly, quickly attaining the lethal temperature range. Higher maximum soil temperatures were obtained for dry soils than for wet soils, however, and dry soil conditions must be considered typical of most wildfire events in California.

SOIL NUTRIENTS

In his review of fire in chaparral, Leonard DeBano reported that prescribed fire's effects are more extreme in chaparral than in forests because prescribed fires burn the canopy extensively. Chaparral fires tend to affect the physical, chemical, and biological properties of soils. Soil structure and cation exchange capacity change as organic matter is combusted. Availability of nitrogen and phosphorus to plants is particularly affected by soil heating, and fires often volatilize large amounts of soil nitrogen. Vaporized organic matter moves downward through the soil and condenses into a water-repellent layer that impedes infiltration, especially in coarse soils characteristic of shrubby vegetation.

Soil microorganisms, which play important roles in plant growth, are highly susceptible to destruction by soil heating.

Nitrogen released by fire and deposited on the surface in ammonia form often gives a nutritive boost to postfire vegetation establishment. Nitrogen release diminished the need for, and the value of, fertilization immediately following a fire. Once the short-term flush of nitrogen availability ends, however, a long-term nitrogen deficiency sets in. These findings suggest that if watershed rehabilitation investments are made in fertilization, they should be deferred for at least one year following the fire. Although processes of soil nitrogen restoration are poorly understood, nitrogen-fixing vegetation such as some Ceanothus species probably play an important role and should be favored in postfire management.

SOIL EROSION

Wade Wells's survey of postfire soil erosion documented how fire initiates a process of soil movement that continues through subsequent rainstorms. During and following fire, dry ravel fills swales and channels with sediment. With the onset of even light rain, overland flows rapidly create rills that evolve into a complex channel system which provides a highly efficient conduit for saturated sediment flows.

Seeding of annual ryegrass has been the traditional strategy for reducing postfire erosion, but evidence provided by Wells, DeBano, and Glen Klock indicates that ryegrass seeding has limited value and may even be counterproductive for re-establishment of native vegetation, especially species of special concern.

Klock's travelogue through time in a watershed in the North Cascades showed how the speed with which nature is able to restore herself depends on natural conditions, such as elevation and moisture availability, and on postfire management decisions, such as how and during which seasons salvage logging occurs.

SOIL HYDROLOGY AND STREAMFLOW

Iraj Nasseri reported that the combined fire effects of vegetation removal and formation of a water-repellent soil layer can increase runoff by from 200 to over 500 percent in southern California's chaparral.

[1]Presented at the Symposium on Fire and Watershed Management, October 26-28,1988, Sacramento, Calif.

[2]Forest economist, Jones & Stokes Associates, Sacramento, Calif.

Peak flows also increase several-fold in response to intense wildfires. Interpreting results of his empirical research combined with simulations using the Stanford Watershed Model, Nasseri found that fires increase the return period of floods associated with moderate and extreme storms. He suggested that flood control structures be designed based on projected runoff from a burned watershed, because fires often give rise to the peak flows that such structures are built to accommodate.

While this observation is extremely apt, I would suggest taking it a step further to remedy a semantic problem of considerable significance. Fires do not lengthen the return periods of floods associated with storms of a specified intensity. Rather, they shorten the intervals between floods of a specified intensity. Flood control agencies such as the U.S. Army Corps of Engineers should recognize the propensity of chaparral vegetation to burn periodically, and consider the effects of such fires in calculating return intervals for floods.

Models for simulating watershed hydrology such as the Stanford Watershed Model and the Sacramento Model, as described by Larry Ferral, are continually enhancing the ability of watershed analysts to project and assess the effects of fires and of several other watershed disturbances of natural and human origin. Such information is critical to urban and regional planning efforts to address the complex problems posed by rapid urbanization of rural lands (as emphasized by Harold Walt in his luncheon speech).

David Parks reported on the hydrologic effects of a forest fire in southwestern Oregon. His results are interesting in part because they contrast significantly with those of Nasseri and others relating to chaparral fires. Parks found that soil hydraulic conductivity, water repellency, and anticipated erosion rates in intensively burned areas varied little in relation to vegetative cover whether the site had been logged before the fire. In fact, intense wildfire was found to have a relatively small overall effect on forest soil hydrology. The increase in water repellency caused by fire in the Oregon forest setting appears small relative to those reported by DeBano and others for chaparral. This difference may be attributable in part to the clay structure of the forest soils. Alternatively, repellency in burned chaparral soils may result from the chemical composition of chaparral vegetation. In any case, based on information presented at this conference, fire-caused soil water-repellency appears to be limited primarily to chaparral soils.

VEGETATION STRUCTURE

Thomas Parker discussed how postfire vegetation structure in chaparral depends on the reproductive strategies of prefire vegetation. Sprouting species generally become re-established faster than species that rely on seed germination. Because reproductive strategies of different kinds of vegetation vary, a diverse flora usually has multiple strategies for postfire revegetation, which increases the likelihood of revegetation success. A diverse flora also reduces risk of wildfire ignition because some of its elements are nearly always green. I would suggest the hypothesis that the benefits of managing for stand diversity are not limited to chaparral but are equally applicable to commercial forest management.

Parker pointed out several implications that revegetation processes have for prescribed fire management. Fire intensity, frequency, season, and diversity of fire-free intervals all affect the rate of establishment and composition of the postfire community. He also noted the importance of fully accomplishing the objectives of a prescribed burn: partial burning may invite a subsequent fire far more destructive than the prescribed burn, or may fail to stimulate germination of desired species.

STREAM TEMPERATURE

Michael Amaranthus and his colleagues found that in a southern Oregon watershed where fire reduced average stream shading from 70 to 10 percent, postfire stream temperatures increased by from 6° to 18° F. Temperature changes were attributable primarily to the increase in solar radiation absorbed by the stream. Temperature increases were also highly correlated with streamflow. Amaranthus found that, in addition to live streambank vegetation and topographic features, standing dead trees were an important source of stream shading, and postfire rehabilitation should retain snags in the riparian corridor.

Watershed analysts whose observations of the political decision-making process have made them somewhat cynical about the significance of their work should take heart from Mr. Amaranthus's report that a forest supervisor changed a streamside salvage harvesting prescription to retain standing dead trees based on the findings of his watershed staff.

IMPACTS OF FIREFIGHTING

We have also seen and heard that fighting wildfires can leave its mark on watersheds. Inevitably, soil disturbance, vegetation removal, and stream sedimentation accompany large movements of firefighters and equipment. Backfires sometimes turn out to be more intense and destructive than anticipated. For example, Logan Norris alerted us to the potential water quality and fishery impacts of fire retardant use, and pointed out the importance of preplanning fire suppression tactics in ecologically sensitive and fire-prone areas.

SUMMARY

It became apparent to me in reviewing these papers that watershed research in and around California has focused primarily on two major vegetation types: the chaparral and the mixed-conifer forest. Some broadening of this focus is especially important when we consider which wildland areas of California are experiencing the most dramatic changes in land use and vegetation cover. I am referring to the foothills of the Sierra Nevada and the Coast Ranges. A sustained commitment by the state to the resource problems of the hardwood range will certainly help focus needed attention on the many watershed-related issues of rapid urbanization. I would expect to see several papers addressing these issues at the next watershed conference.

Papers presented here on the effects of fires on watersheds indicate the major recent gains in understanding of watershed function and response to disturbance. Empirical evidence and comprehensive watershed assessment are replacing casual observation and the narrow doctrinal perspectives of specific scientific disciplines. The opening-up of communication lines between hydrologists, botanists, foresters, soil scientists, and others through this conference and other activities of the Watershed Management Council is particularly encouraging and needs to continue to be fostered by each of us. Although we each have our own agenda and priorities for watershed management and research, we must keep in mind our common goals, among which must be the need to provide future generations with watersheds that work, and by that I mean provide abundantly for both our material and non-material needs.